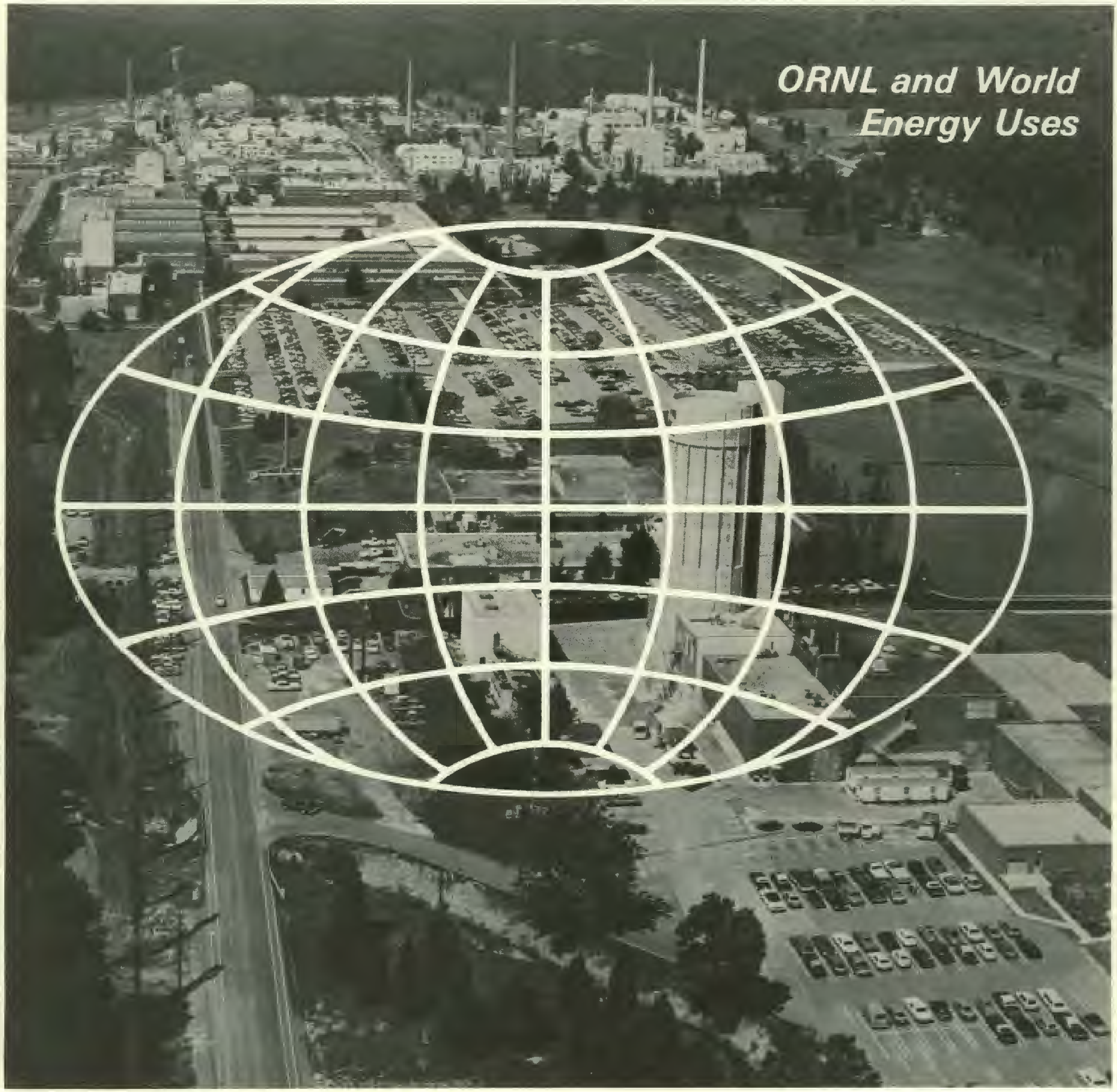
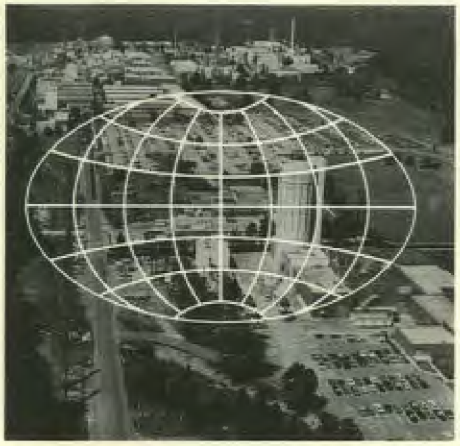
Summer 1982

Oak Ridge National Laboratory review





THE COVER: An aerial view of Oak Ridge National Laboratory

Oak Ridge National Laboratory

review

VOLUME 15 NUMBER 3 **SUMMER 1982**

FOUR DECADES OF ORNL ACHIEVEMENTS
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The *Review* is published quarterly and distributed to employees and others associated with the Oak Ridge National Laboratory. The editorial office is in Building 4500-North, Oak Ridge National Laboratory. P.O. Box X, Oak Ridge, Tennessee 37830. Telephone: Internal 4-7183; commercial (615) 574-7183; FTS 624-7183.

ISSN 0048-1262

OAK RIDGE NATIONAL LABORATORY
OPERATED BY UNION CARBIDE CORPORATION · FOR THE DEPARTMENT OF ENERGY

EDITORIAL

Nineteen hundred and eighty-two is the year of the World's Fair in Oak Ridge's neighboring city, Knoxville. It is an energy exposition, and no institution in East Tennessee is more broadly or more deeply involved in energy than is Oak Ridge National Laboratory. We expect a large number of visitors from all over the world this summer. Many of them will be curious: what does a large national laboratory actually do, what do its scientists and engineers know about the energy problems, and what solutions are being worked on? This issue of the *Review* is in part addressed to the visitor. Two articles deal broadly with energy. The first, "Energy Transitions," written by Truman Anderson, outlines global energy issues for the interested Fair visitor, even as it provides insight to the ORNL staff member. Don Trauger, in "Electricity: Faithful Servant at the Flip of a Switch," writes about electrical energy, our most rapidly growing energy sector, which has been at the heart of the ORNL program from the beginning. On the remaining pages you will find an assortment of the more noteworthy achievements of Oak Ridge National Laboratory.

If anything shines through these pages, it is the diversity of research and the responsiveness to national goals of the many scientific and technical accomplishments of the Laboratory. It all began in the early 1940s with a single mission: pilot-scale production of plutonium and its chemical separation from uranium and fission fragments. From this narrow base the Laboratory evolved into the world's largest multipurpose laboratory engaged in energy research. The objective is no longer related to weapons; the current tasks are to develop and improve energy sources, to increase the efficiency of generation and consumption of energy, and withal to ensure environmental quality and health. This role is accomplished by a broad-based and effective staff of 5000 employees: among them are 650 engineers, 600 physical scientists, 300 biomedical and environmental scientists, 40 social scientists, and 20 mathematicians.

The Laboratory is not a cloistered society. It interacts with the country's university and industrial communities in uncounted ways. This year, about 1200 scientists from various institutions throughout the world will spend time at ORNL to carry out research, in collaboration with our staff, using some of the most modern of research equipment. In addition, another 1000 visitors a year from industry will come to collect information and gain understanding in specialty fields or to acquaint themselves with the broad questions related to energy production and use.

The spectrum of research is necessarily broad; it leads to new ideas and new concepts but stops short of commercialization. Technology draws on the basic sciences, and technology, in turn, is organized to address energy development. With its mixture of advanced technological research, discovery of new scientific facts, and concern for human health and the global environment, the Laboratory plays a pivotal role in the nation's long-range energy picture.—A.Z.

Energy Transitions

By TRUMAN ANDERSON

It was just about dusk as the small figure knelt to place blades of dry grass on the dying embers. Every careful movement, from laying the tinder to softly blowing the coals, suggested this was an important fire. It *was* an important fire. All day she had carried it at the end of smoldering sticks. It was her responsibility, and she had done well. The fire would extend the day and protect the night. Over its flames, the band would cook their bounty of frogs, snakes, lizards, and snails collected on the trek to the new encampment. Her mate and the other males would use it to char the ends of long, straight sticks to make them easier to sharpen with stone scrapers, for tomorrow was the day of the buffalo. Lizards are good, but buffalo is better. The torch of this fire would be used to set aflame the tall grass extending from the swamp. With luck, the dim-witted buffalo would stampede into the bog. Death administered by the sharp sticks would not be quick, but it would be sure.

She could not know that the cultural development of capturing, preserving, and using natural fire had allowed her kind to spread far beyond her East African homeland—north to the Mediterranean and even into the temperate zone of north China. Neither could she know that millions of fires before had already changed the facial structure of her species and that millions of fires to follow would change it even more. The sloping forehead, the large brow ridge, and the muscular jaw set with oversize teeth would give way to a smooth face, small jaw, and real chin. Already, the tenderizing fire had made the powerful, chewing jaw unnecessary. She was female, but she was not yet woman. That transformation would take another half million years.

The Fires of Revolution

The mastery of wood-fed fire literally changed the face of man. But man's use of fire (energy) just as literally changed the face of the earth. The Neolithic Revolution (invention of agriculture) some 10,000 years ago allowed mankind to broaden his domain, expand his numbers, develop specialties, and create cities. These advancements were accompanied by a large increase in energy use relative to that of the preceding hunter-gatherer cultures. But, again, the energy was mostly derived from wood, and the applications were not dramatically different than those of man's ancient, near-human ancestors.

If success is measured by numbers, the Industrial Revolution, dating from the middle of the 18th century, was the most important of all of man's cultural innovations. Before that, the mastery of tools and fire had allowed him to inhabit the earth—but very, very slowly; the time required for populations to double was perhaps 50,000 years. The invention of agriculture represented another turning point in population growth; the doubling time decreased to roughly 1000 years.

At the beginning of the Industrial Revolution the world population was less than 800 million. Now, in 1982, we stand at 4500 million with a doubling time of less than 40 years. The people added to the earth every two days would create a city the size of Knoxville.

The engines of the Industrial Revolution, fueled initially by wood, could not be sustained by it. Coal became the fuel of industrialization. In light of today's concern about the environmental effects of coal, it is ironic that this fuel was probably the savior of the natural environment. A wood-driven Industrial Revolution would probably have caused deforestation, erosion, and general environmental degradation well beyond any experienced in today's industrial nations.

Considering that wood was the fuel of man and pre-man for at least a million years, the speed with which it became a minor fuel in the industrial nations is quite remarkable. As late as the Civil War, the United

"Most of the [developing country energy use] increases have been for serving basic human needs, not for leisure-class luxuries."

Truman Anderson heads ORNL's Program Planning and Analysis Group.

States, a latecomer to industrialization, derived more than 80% of its energy from wood.

Forty years later, as we entered the twentieth century, wood's share had dropped to about 20% and that of coal had increased to over 70%. It is not entirely accurate to say, however, that coal displaced wood in the United States; the quantity of wood consumed declined very slowly. Coal simply provided the increasing demands of industrialization. Neither is it accurate to say that the first energy transition—that from wood to coal—was a world phenomenon. It was, rather, a phenomenon of the industrialized world.

For many nations, the transition from wood is yet to come.

Although the popular image of industrial societies of the 19th century is one of grimness, the reality must have been less grim than what came before. Better housing, clothing, and food and advances in the health sciences resulted in increased life expectancy and population growth in the nations that participated in industrialization.

It was not long before spin-off from the industrial countries began to affect the rest of the world. Within the first quarter of the 20th century, population growth in nations still deep in the Neolithic Age started to exceed that of the industrial countries. This phenomenon intensified following World War II; it now characterizes present world population growth and is expected to do so well into the future.

Fuels of Wealth and Poverty

The post-World War II era, in addition to being marked by large population growth in the less developed countries, saw large increases in world energy consumption. But the workhorse of the industrial revolution—coal—was displaced from its position as the world's major commercial fuel by oil, which now provides nearly half the world's commercial energy supply. This increased dependence on oil led to rapid price increases in the 1970s and to increased political and economic power for those relatively few countries that produce oil for the world market.

Although some recent discussions of energy use tend to portray the increased energy demand of the post-war era as a bad thing, such arguments tend to be based on philosophies well outside the mainstream of human values. To most people, the trend in energy use was a very positive development in that it allowed reconstruction and vigorous economic growth in the war-torn industrial nations. But more important, most of the less developed countries were able to survive without reductions in living standards, despite huge increases in their populations over the same period.

Some of these countries have even been able to make real gains in national and personal prosperity. The poorer countries and regions that have made progress toward development in the past quarter of a century have done so with substantial increases in the amount of energy used. For instance, energy use increased by a factor of 14 in China, by a factor of 8 in Latin America, and by a factor of 11 in Southeast Asia. Most of the increases have been for serving basic human needs, not for leisure-class luxuries. For example, "the green revolution" that was achieved over the past 15 years resulted from the development of dwarf varieties of wheat and rice that could benefit from irrigation and fertilization. Without these energy-related inputs, the new varieties of grain would have been less productive than the domestic varieties they replaced.

Recent world trends in energy use and food production in the poor nations give cause for hope; however, much of the world still lives in desperate poverty. The number of people suffering from severe malnutrition

". . . if worldwide living standards are to improve, energy usage must grow much faster than population."

exceeds 500 million, and the United Nations estimates that 5 million children die of starvation annually.

The fuel of the poor is man's traditional energy source—wood. The daily headlines about oil over the past decade have obscured the fact that in many parts of the world the real energy crisis has become wood, not oil. As rural populations have expanded, firewood has been used faster than it has grown. One result is deforestation, erosion of topsoil, and loss of land productivity. A further consequence has been another of man's energy transitions, this time from wood to animal dung. This transition removes manure from its vital role as a soil conditioner and fertilizer, further weakening land productivity. Just as wood could not sustain the Industrial Revolution, neither can it sustain a world touched by the Industrial Revolution but not yet a part of it. The "inexhaustible" fuels are being exhausted.

The Future

The future of possible world progress, and the implications for energy, are dealt with in two recent energy studies—one by the International Institute for Applied Systems Analysis (*Energy in a Finite World*, Ballinger Publishing Company) and the other by the Oak Ridge National Laboratory (*A Desirable Energy Future*, Franklin Institute Press). Although the studies differ somewhat in perspective and approach, the broad conclusions are the same and for the same reason—the desire to provide an increased standard of living for many more people.

World population will about double in the next half century, and about 90% of the growth is expected to be in those nations now classed as less developed. Adequate food for such a number, not to mention improved human living standards, requires efficient agriculture, crop storage, and food processing and distribution. These are all energy-intensive activities. Similarly, energy consumption will have to increase as industrial activity increases, no matter how efficient the industrial processes become.

In short, if worldwide living standards are to improve, energy usage must grow much faster than population. The ORNL study suggests that if the less developed parts of the world are to make significant progress, world energy production must increase by up to a factor of 6 within the next 50 years, even if conservation is emphasized.

One obvious question is whether energy resources are adequate to provide such a large increase in demand. If we limit our perspective to traditional sources of gas and oil, the answer is "no." The world production capacity for both these fuels will very likely fall short of demand late in this century or early in the next.

But if we look to other resources, such as coal and nuclear energy, the answer is "yes." The world has enough conventional energy resources amenable to known methods of extraction and use to last well beyond the middle of the next century. This does not include the unconventional resources, such as oil shales and heavy crudes, which are also extensive. In addition, the options will almost surely be broadened by future developments in fusion, solar, and breeder reactor technologies, for example.

We are thus facing a future of greatly expanded world population, but also, we have reason to hope, a correspondingly expanded world energy supply. As with population, most of the increases in energy demand will be in nations that are now classified as less developed. The needed energy cannot come from the same resource base that allowed the expansion of the last few decades. We must make a transition from our present situation, in which growth in demand has been met largely by natural oil and gas, to one in which we resort to more abundant resources to provide most of our energy.

"... the relationship between nature and man has never been very harmonious, and man's historical struggle has been to erect a shield between himself and nature."

Energy Myths and Realities

Prometheus was one of the gods assigned the task of giving to the animals all the powers they needed. When it came man's turn, there were no gifts left. To correct this deficiency, Prometheus stole fire from the lightning of Zeus and gave it to man, whereupon Zeus had Prometheus chained to Mount Caucasus. Each day a vulture came and tore at his liver, and each night the liver grew again. This went on for thousands of years until Hercules killed the vulture and freed Prometheus.

The Greeks had their energy myths and so does modern man. The modern mythologists believe that man should be very conservative in his use of energy—especially the "unnatural" kinds derived from coal, uranium, and oil shales (could these be the divine possessions of the gods?). The future needs of man are, they state, to be provided by conservation and renewable energy forms derived from the sun. By this means man could devise a system that is sustainable for all times; he would, presumably, live in harmony with nature.

These ideas seem to have strong appeal, especially among intellectuals of the wealthy nations. They have less appeal among those who have actually lived in "harmony" with nature. The fact is that the relationship between nature and man has never been very harmonious, and man's historical struggle has been to erect a shield between himself and nature. When he has been successful, he has enjoyed a long and prosperous life. When not, nature has proved to be an unkind partner.

Conservation—in the sense of increased human benefit per unit of energy use—has been one of the most outstanding features of industrial societies in this century. For example, in the United States (considered by some to be the most "wasteful" of nations), the per capita energy consumption today is only 70% higher than it was in 1920. Yet, during this period, the gross national product per capita grew by 350%.

Further improvements in energy efficiency in the future are both desirable and inevitable. However, even with strong emphasis on conservation, world energy needs will increase several-fold in the next 50 years. Conservation is vital, but any energy strategy that does not also emphasize supply is a blueprint for human disaster.

The proposed approach to satisfying future energy needs through renewable energy forms derived from the sun involves biomass (wood, organic wastes) to a considerable extent. The problem with this approach is apparent. Biomass is already being used extensively in much of the world, and the consequences of overuse are serious. As pointed out previously, in some parts of the world the use of biomass appears to be the problem rather than the solution. Let us not advise the poor that the disease is the cure.

Concluding Remarks

The evolution of man—both biologically and culturally—has been closely tied to and strongly influenced by energy. The future course of human events will be determined by how sensibly we deal with energy. The future needs will be great, but the world has sufficient energy resources to supply increasingly large demands for at least the next 50 to 75 years.

Some concern exists that exploiting these resources, and in particular the fossil resources, may result in serious environmental impacts. However, in considering the potential environmental risks of producing and using energy, one must also examine the certain human risks of not doing so. In a growing world, much of which is already underfed and poorly housed, the humanitarian answer will most certainly be both the efficient use and increased production of energy.

Bioreactors like this one have been developed at ORNL as an energy-efficient technique of cleaning up liquid wastes, recovering valuable resources, and producing alcohol fuel from biomass. The researcher is injecting a culture of bacteria into the bioreactor.

The portable fast analyzer can be used to type blood at a patient's bedside or to measure concentrations of environmental pollutants in creeks.

Technology for Health and the Environment

Oak Ridge National Laboratory has been responsible for numerous innovations that are or could be used for protecting human health and the environment.

The zonal liquid centrifuge, invented at ORNL with support from the Oak Ridge Gaseous Diffusion Plant, was first used commercially in 1967 to produce the ultrapure flu vaccine, Zonamune. Zonal centrifuges based on ORNL designs are still being manufactured and sold to U.S. and foreign vaccine-manufacturing industries that centrifuge vaccines to remove impurities that could cause harmful side effects in patients.

In 1968 the first of a series of centrifugal analyzers was invented at ORNL. One of ORNL's most famous innovations, this device revolutionized the speed, accuracy, and sensitivity with which medical diagnostic tests and other analyses can be performed. Several thousand fast analyzers based on ORNL designs are now used in hospitals and clinics to measure certain constituents in body fluids that will allow diagnosis of a variety of diseases.

Because the primary research focus at ORNL in the 1940s and 1950s was nuclear-related, numerous instruments were developed to measure employees' radiation exposure and to warn of hazardous radiation levels. Most famous of the devices invented at ORNL were the red-nosed neutron dosimeter nicknamed "Rudolph" and the pocket "chirper," a personal radiation monitor that chirps in response to gamma radiation. They are still used in the nuclear industry today.

Burn therapy was advanced in 1977 when an ultrasonic transducer was developed that uses sound waves to determine the depth of a burn and the extent of tissue damage. The device is being used today in burn clinics to aid doctors in deciding whether skin grafts or some other treatment is needed.

ORNL is responsible for several developments that offer hope for improved monitoring and surveillance of workers in industries that convert coal to liquid and gaseous fuels. These advances are based on the principle that some potentially carcinogenic organic chemicals produced in coal conversion absorb ultraviolet light and subsequently give off visible light. Instruments developed at ORNL can detect on surfaces trace amounts of chemicals that may cause cancer, can more safely detect contamination of human skin by coal-derived liquids, and can identify and measure the amount of specific gases and vapors in the coal workers' atmosphere.

In addition, ORNL has developed a pen-size dosimeter that allows rapid and sensitive detection of airborne pollutants in the coal workers' environment. The device consists of filter paper pretreated with special chemicals; vapors adsorbed by the paper can be identified and measured to give accurate dosages of toxic vapors inhaled by each worker.

Biotechnology, the controlled use of living systems or their active fractions to bring about desired chemical and physical change, is one of the most ancient of technologies, beginning perhaps with beer and wine fermentation as far back as 2000 B.C. Since 1963, when the Laboratory first engaged in biotechnology research to produce and recover gram quantities of transfer RNA for research in molecular biology, ORNL has found innovative ways of using bacteria to convert harmful chemicals to harmless ones for applications in pollution control.

One ORNL development successfully treats liquid nitrate wastes, a continuing environmental problem in several industries, including the production of nuclear fuel. Using garden soil bacteria attached to agitated coal particles in a column, researchers have developed a process now being successfully used at pilot plants at a nuclear materials processing center and a uranium enrichment facility in Ohio. The pilot plants reduce nitrate concentrations to levels acceptable for release to the environment.

ORNL also has developed an energy-conserving wastewater treatment system called ANFLOW in which oxygen-shunning (anaerobic) bacteria are attached to fixed plastic packing in a column. A demonstration ANFLOW plant is now operating successfully in Knoxville. Because ANFLOW systems operate anaerobically, they produce less sludge and do not require energy-consuming aerators. ANFLOW systems also convert much of the waste material into the gaseous fuel, methane. Thus, such systems may even be net producers of energy.

Acrostic Puzzle

1 L	2 A	3 K	4D		5 J	6F	7 N		8 L	9 E	10 N	11 J	12 B	13 F	14 Q		15 O	16 G
17 I	18 Q		19 I		20 D	21 X	22 Q	23 S	24 R	25 Z	26 N		27 Q	28 D	29 S	30 Q	31 L	32 Y
33 O		34 Q		35 R	36 C	37 E		38 Q		39 S	40 Q	41 T	42 C	43 E	44 R		45 D	46 Q
	47 R	48 Q	49 B	50 S	51 X		52 Q	53 K		54 Q		55 Q	56 B	57 D	58 S	59J	60 W	
61 R		62 H	63 U	64 M		65 K	66 E	67 J	68 Q	69 O		70 Z	71 Q	72 A	73 C	74 J		75 U
76 W	77 F	78 Q		79 Q	80 F	81 T		82 A	83 R	84 B	85 D	86 E	87 V	88 Q	89 W		90 H	91 D
92 L		93 Q	94 D	95 J		96 N	97 T		98 G	99 Q	100 P	101N		102Q	103R		104O	105U
106T	107W	108Q	109Y	110B		111P	112N	113C	114D		115O	116P	117I	118U		119X	120V	121T
122U	123F	124H	125Y	126N	127O		128A	129G	130B	131C	132H	133Y	134N		135S	136Y	137Z	138V
139P	140E	141T		142Z		143W	144M	145Z		146L	147M	148P	149Y	150P		151X	152Z	153P
	154K	155B		156W	157Q	158P	159A	160J	161A	162F	163D		164V	165H	166Q		167U	168P
169V	170R	171B	172I		173H	174V		175Q	176X	177V	178C		179Q	180A				

ANSWER ON PAGE 33

How to solve this puzzle:

Guess the words defined here and write them over their numbered dashes. Then transfer them to the appropriate numbered squares in the grid. When the grid is filled, a quotation can be read from left to right; black squares indicate the ends of words. The initial letters of the guessed words under Definitions will spell the author of the quotation and its subject matter.

Definitions

A. 360° horizontal arc ... 159 161 82 128 72 180 2

B. Liturgical praise ... 84 155 49 56 130 12 171 110

C. Substance having marked basic properties ... 113 73 178 36 131 42

D. Word describing East Tennessee ... 20 57 85 26 114 28 45 4 94 91 163

E. Under the weather ... 88 66 9 43 140 37

F. Fu______ ... 13 162 123 77 80 6

G. Ethnic; approximately (suffix) ... 129 16 98

H. Morsel ... 124 132 62 90 165 173

I. Cast ... 172 117 19 121 17

J. "______ and two to go:" expression denoting the completion of the first of three tasks (2 wds) ... 5 160 67 74 59 95 11

K. Hildegarde ______, German film actress ... 154 3 53 65

L. Chirp ... 92 1 8 31 146

M. U.S. secretary of state under McKinley ... 147 144 64

N. Novel by Samuel Butler ... 126 7 101 96 112 10 134

O. Virgin ... 115 127 15 33 104 69

P. Novel by Booth Tarkington ... 116 148 100 150 168 111 139 153 158

Q. R&D locale (4 wds) ... 71 38 78 175 179 18 166 48 46 54 79 55 157 93 34 22 68 99 27 108 30 102 40 52 88 14

R. Flood ... 24 83 170 103 35 61 47 44

S. Body of work ... 23 50 135 58 29 39

T. Uneven ... 81 41 106 141 97

U. Fold ... 105 75 122 63 118 167

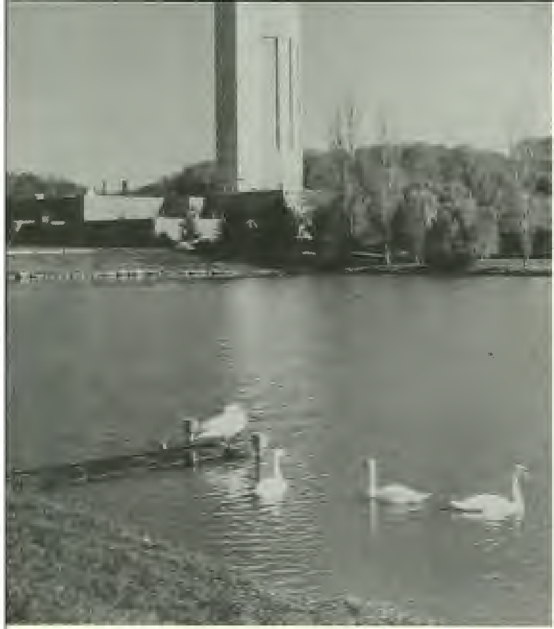
V. Ale month ... 174 177 87 169 164 120 138

W. Not a soul ... 107 76 156 60 143 89

X. Musical instruction denoting alternative passage (It.) ... 176 119 51 21 151

Y. Esprit de corps ... 109 133 149 136 32 125

Z. Edible weed ... 145 142 137 152 25 70



The Holifield Heavy Ion Research Facility at Oak Ridge National Laboratory.

In this view of Oak Ridge National Laboratory in the 1940s, the Graphite Reactor is at the center.

Research Facilities

Over the years, ORNL has had many research facilities, a few of which have become international as well as national treasures. Some of these are user facilities—that is, the facilities are available to researchers all over the world. Here are some highlights about ORNL's better known facilities.

The *Graphite Reactor* was built in 1943 as a pilot plant for large-scale plutonium production reactors at Hanford, Washington. (The atomic bomb dropped August 9, 1945, on Nagasaki, Japan, was fueled by plutonium from Hanford.) This 1-MW air-cooled pile, now a national historic landmark, was the world's first operating nuclear reactor to produce sizable quantities of heat and one of the nation's first reactor sources of radioactive isotopes used in agriculture, industry, medicine, and research.

The *86-inch cyclotron* produced the world's most intense proton beam in 1950. Besides being used for studying nuclear reactions and radiation damage in materials, it produces valuable radioisotopes, including gallium-67, which is employed in the diagnosis of bone cancer, and carbon-11, which is used for detecting tumors and disorders in the pancreas and brain.

The *63-inch cyclotron*, first operated in 1952, was the world's first cyclotron to accelerate heavy ions. It produced evidence that put to rest fears that explosion of a hydrogen bomb could ignite the earth's atmosphere.

The *Oak Ridge Research Reactor*, which has a design power of 20 MW, produced the highest neutron flux in the world in 1958 when it went critical; it replaced the Graphite Reactor as the main source of radioisotopes.

The *High Flux Isotope Reactor*, one of six ORNL reactors, is the world's most powerful research reactor and has the world's highest thermal-neutron flux (neutrons per square centimeter per second). It produces elements heavier than uranium by neutron bombardment of target material such as americium, curium, and plutonium. Samples from HFIR have been used by scientists throughout the world to study chemical and physical properties of new materials not found in geologic samples because of their short lifetimes.

HFIR is the principal free-world source of californium-252, a compact, intense source of neutrons used both to destroy tumors and to start nuclear reactors. Since achieving its full power of 100 MW in 1966, HFIR has an operating reliability unsurpassed by any other reactor in the United States. It is the site of the new National Center for Small-Angle Neutron Scattering Research, which is supported by the National Science Foundation.

The *Oak Ridge Electron Linear Accelerator*, completed in 1968, is a powerful source of neutrons (produced by electron bombardment of tantalum targets) used for cross-sectional measurements to aid in the design of reactor shields and liquid-metal fast breeder reactors.

The *Oak Ridge Isochronous Cyclotron*, first operated in 1962, is now part of the Holifield Heavy Ion Research Facility. ORIC's beams of protons, deuterons, and helium were being used to characterize nuclear energy levels and to quantify nuclear models.

The *Holifield Heavy Ion Research Facility* is an international user center for research on the interactions between heavy nuclei. By studying these interactions, researchers hope to shed new light on the fundamental nature of atomic nuclei. The facility holds the world's record for producing the highest man-made steady voltage (second only to lightning). Participants in early experiments have come from China, Denmark, India, Portugal, Sweden, United Kingdom, and West Germany.

The *National Environmental Research Park*, a 5500-ha (13,000-acre) site, has long been an outdoor laboratory in which instrumented experiments are conducted. The U.S. government now protects the area for research and education in the environmental sciences.

The *Aquatic Ecology Laboratory* consists of indoor tanks and outdoor ponds for studying the environmental effects of energy production, including synthetic fuel spills, on fish and other aquatic life.

An ORNL researcher uses neutron counting technique to study physical and chemical properties of thermal insulation.

These experimental houses in Knoxville demonstrate the relative efficiencies of various approaches to space heating and cooling. The house at right uses conventional systems, the center house uses solar energy, and the house at left relies on the Annual Cycle Energy System developed at ORNL.

ELECTRICITY MATCHING QUIZ

Match the name with correct sentence.

1. ___Thomas Edison of the United States	a. He made the first crude battery.
2. ___Hans Christian Oersted of Denmark	b. He measured materials resistance to the passage of electrical current.
3. ___Andre Ampere of France	c. His equations are basis of electrical theory.
4. ___George Simon Ohm of Germany	d. He discovered that dissimilar contacting metals generate small electrical currents.
5. ___Luigi Galvani of Italy	e. He discovered that wire carrying electrical current produces a magnetic field.
6. ___James Clerk Maxwell of England	f. He invented the light bulb and phonograph.
7. ___Allesandro Volta of Italy	g. His name is used for our unit of electrical current.

ANSWER ON PAGE 28

This heat pump-water heater being installed at ORNL's Energy Conservation Laboratory was developed by industry under ORNL's guidance and is now available commercially. It saves up to half of the energy used by a conventional resistance-type electric water heater.

Energy Conservation

In 1971 when the U.S. Congress authorized the national laboratories to develop "more efficient methods to meet the nation's energy needs," ORNL started its first studies of reducing energy demand—a significant departure for a laboratory that had focused on increasing energy supply.

Efficiency of energy use was studied at the Laboratory as early as 1962 when ORNL's nuclear desalination program received international attention for its studies on using waste heat from nuclear power plants to desalt seawater for irrigation in arid, coastal nations. This concept of cogeneration—simultaneous production of electricity and heat—was later pursued at ORNL in studies in which waste heat was used to warm ponds and greenhouses for raising edible fish and vegetables. Today it is the basis for a district heating scheme in Minneapolis–St. Paul, Minnesota.

ORNL conservation studies sponsored by the National Science Foundation in the early 1970s found that (1) the efficiency of air conditioners could be doubled without significantly raising their cost and (2) if Americans insulated their homes 20% above current government standards, they would decrease energy consumption for space heating by 20%.

Two years after the 1973 Arab oil embargo forced the United States to examine ways of cutting back on energy consumption and using energy more efficiently, ORNL developed the Annual Cycle Energy System (ACES), a heat pump that extracts heat from an insulated tank of water in winter, changing it to ice for cooling in summer. Tests of ACES in several houses, including one near the Knoxville airport, showed that it uses less than half the energy required by the best air-to-air heat pump. Although its initial cost is high enough to discourage installation by the average homeowner, ACES' ability to keep demand down during hours of peak electrical consumption makes it attractive from the point of view of utilities whose peak power costs are much higher than their base-load costs.

Working with private industry, ORNL guided the development of energy-efficient appliances that could help reduce residential energy consumption, which makes up one-fourth of U.S. energy use. A heat-pump water heater that uses only half as much energy as the standard electrical resistance water heater is already on the market. ORNL also instigated the development of a refrigerator-freezer which uses 40% less energy than the most efficient units being sold.

ORNL conservation studies have looked at ways of saving energy by (1) running power lines in underground pipes containing a special insulating gas that permits extremely high voltages, thus minimizing resistive losses; (2) injecting winter-chilled or hot wastewater into aquifers for subsequent use for cooling or heating of buildings; and (3) incorporating special phase-change materials in the walls and ceilings of houses that absorb heat from the sun and release it for space heating during the colder times of day.

To reduce energy losses by taking advantage of stable underground temperatures, ORNL built the Joint Institute for Heavy Ion Research as an innovative earth-sheltered building with a passive solar design. The building's windows are equipped with reflective-insulating blinds designed at ORNL. By reflecting sunlight toward the ceiling or away from windows, the blinds can enhance space heating in winter and reduce air-conditioning loads in summer and nighttime heating losses.

ORNL managed the technical aspects of the Residential Conservation Service and developed a home energy audit to help Americans select cost-effective conservation measures, such as insulation. Research on insulation properties included development of a unique screen heater technique to measure the resistance to heat flow of both pipe and building insulations.

ORNL developed computer models to forecast energy demand in the U.S. residential and commercial sectors through the end of the century. Modeling led to the conclusion that demand for energy in the residential sector will decline due to factors such as slower population growth and rising fuel prices. In the early 1970s ORNL researchers were among the first to predict correctly that demand for electricity would drop as power prices increased, despite the rise in population and average income; in fact, the increase in demand for electricity has declined from 6 to 1% per year in the last ten years.

ORNL also studied health impacts of indoor air pollution, a problem aggravated by energy conservation measures that seal up homes and reduce ventilation. Indoor pollutants that could be hazardous to health are nitrogen dioxide and carbon monoxide from gas and wood stoves, radioactive radon from soil and well water, and formaldehyde which is present in particle board and urea-formaldehyde foam insulation. ORNL has developed several simple devices for measuring the doses of various indoor pollutants. Correlation of such measurements with health effects such as respiratory problems could influence the setting of ventilation standards.

Plant ecologists study the effects of simulated acid rain on kidney beans in growth chambers. Early results indicate that plant growth is reduced by acid rain used in laboratory studies.

The Environmental Sciences building and greenhouses at ORNL.

Energy Impacts on the Environment

ORNL has the world's largest environmental laboratory, which enjoyed considerable growth in the past decade after a federal judge decided in 1971 that the government was required to prepare environmental impact statements for nuclear power plants in operation as well as those on the drawing board. Later, nonnuclear as well as nuclear plants were assessed by ORNL for both environmental and socioeconomic impacts (such as increased property tax revenues and greater demand for social services).

Ecological studies actually started at ORNL in 1954 with the examination of radiological effects on insects and the uptake in vegetation of radioactivity from buried nuclear wastes. Environmental research was not officially launched at ORNL until 1967 when Congress directed the national laboratories to perform work "relating to the protection of public health and safety."

In 1968 ORNL ecologists led and participated in the first large-scale integrated ecological research program, known as the International Biological Program. ORNL coordinated projects involving hundreds of ecologists working in the Eastern Deciduous Forest Biome.

In the past 12 years, ORNL ecologists have studied the impacts of power plant cooling systems on the environment. In thermal pollution studies, aquatic ecologists examining the effects on fish of elevated water temperatures provided data used in setting water temperature limits and in analyzing the environmental impacts of nuclear and fossil fuel plants. ORNL researchers developed fish tags—electronic thermometers which transmit sound waves from fish to indicate either fish body temperature or water temperature so that ecologists can ascertain the temperatures preferred by fish in the natural environment.

Chlorine is used to protect power plant cooling systems from fouling organisms to avoid a decrease in electricity generation. ORNL found that chlorine-containing organic compounds believed to be potentially toxic or carcinogenic are hazardous to fish but only in concentrations not commonly found near power plant cooling systems. A model developed by ORNL for predicting the toxicity of residual chlorine compounds has been used by the federal government for setting chlorine discharge limits at power plants.

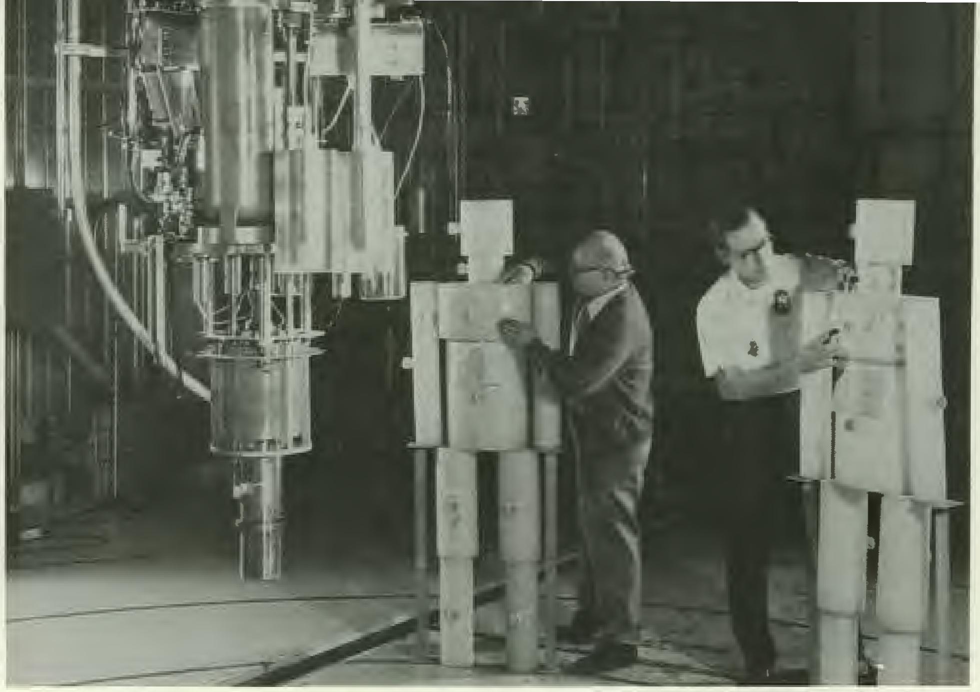
Fish can be killed if trapped by or sucked into power plant cooling systems. ORNL computer models developed to assess the effects on fish of power plants in New York influenced the selection of fish protection devices required as part of the resolution of the ten-year Hudson River Power Case.

Recently, ORNL has studied the environmental impacts of burning fossil fuels and converting coal to liquid and gaseous fuels. Acid rain, which has made some lakes in Europe and the United States uninhabitable by fish, is formed from discharges of sulfur dioxide and nitrogen oxides, and increasing concentrations of atmospheric carbon dioxide could cause a global climatic warming that might result in changes in vegetation patterns and flooding of coastal lands.

Using laboratory rain up to 40 times more acidic than normal rain, ORNL researchers found that simulated acid rain causes reduced plant growth in kidney beans. Field studies, however, have yet to confirm acid rain damage to regional crops.

In response to the carbon dioxide concern, ORNL ecologists have tried to reconstruct past climate and effects on vegetation by studying the period 5000 to 8000 years ago when the climate was warmer than now. They found that oak and hickory trees replaced pine and spruce forests in the southeastern United States, an indication of vegetational changes that might also result from a climatic warming induced by carbon dioxide.

Computer models developed at ORNL in the 1970s simulate the effects of air pollution and acid rain on forest growth, the effects on water yield and quality of growing and harvesting forests for biomass energy production, the environmental effects of radionuclide migration from disposal sites, and the effects of toxic chemicals on forests and farms.



Plastic human-like phantoms decked out in dosimeters have been built at ORNL and placed near a radiation source. They have provided data that are compared with calculations of the doses to organs in humans exposed to various levels of radiation.

Radiation and Health

In the wake of the atomic bomb's destruction of Hiroshima and Nagasaki, questions arose about the effects of radiation on Japanese survivors. Later, answers were sought about possible radiation effects on humans from atomic bomb test fallout, x rays and radioisotopes used for medical tests and treatment, and nuclear power plants. Since the 1940s ORNL biologists have been involved in assessing the health effects of radiation.

In the late 1940s ORNL biologists discovered that the oxygen effect—the increased probability of cell damage due to the presence of oxygen—could be counteracted by several oxygen-removing chemicals that seem to protect against radiation damage.

Radiation effects studies at ORNL in the mid-1950s focused on mouse embryos at different stages of development. Results alerted doctors to hazards of administering x rays to women who may be in the early stages of pregnancy and not know it. This led to the recommendation that diagnostic radiation be timed in relation to the menstrual cycle.

In 1958 a revolutionary finding was made in ORNL's radiation genetics program, which had begun ten years earlier. It was discovered that for a given dose of radiation, the mutation rate in mice is lower at low dose rates than at high dose rates. The mutation rate for chronic irradiation was found to be one-third that for acute radiation.

In the early 1950s the specific-locus test was developed for estimating the risk of damage to human genes from radiation. The mutation rate is measured for seven genes at specific loci of mouse chromosomes at which mutations produce easily recognizable traits such as altered coat color.

In the 1970s an analysis was made of a series of skeletal mutations found in first-generation offspring of irradiated mice. It was determined that the effects of these dominant mutations closely resemble those of certain hereditary disorders in human beings. Thus, the results of these analyses can be directly applied to projections of hereditary effects of radiation. Data from both the specific-locus and skeletal-mutation tests have been used by national and international commissions in estimating the genetic hazard to humans from low-level radiation.

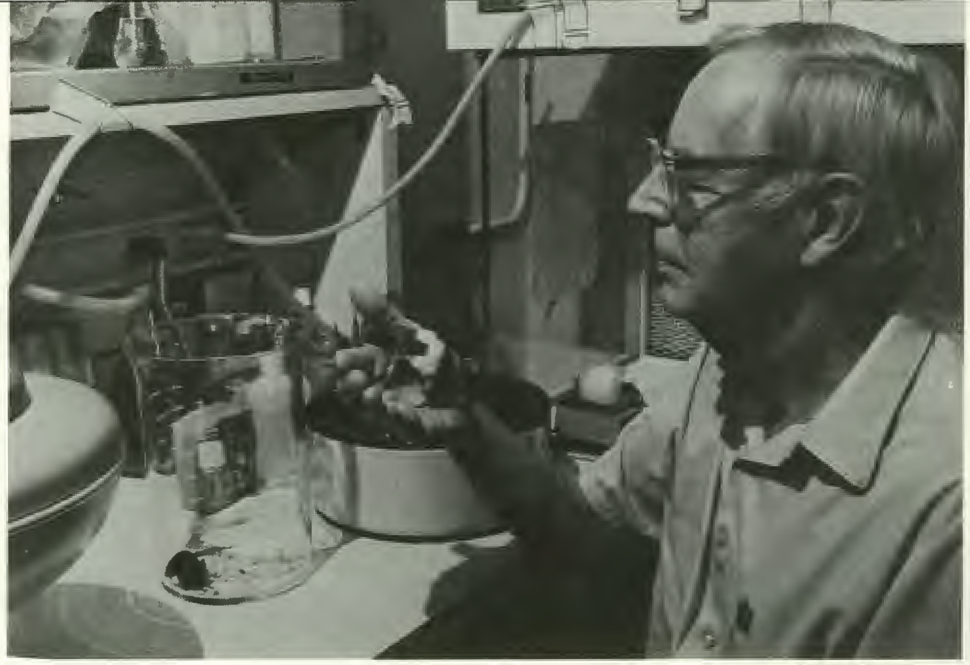
ORNL geneticists have shown that the reproductive cells of the mouse possess repair systems that can lessen (but not eliminate) the genetic hazard at low doses and dose rates of radiation. Using radiation as a research tool, they studied basic genetic mechanisms in mammals and developed most of the currently available mammalian mutagenesis tests used throughout the world for assessing hazards of various environmental agents.

By measuring the radiations from nuclear bombs at the Nevada Test Site in 1955, ORNL health physicists were later able to determine radiation doses to survivors of the atomic bombings of Hiroshima and Nagasaki. They also developed neutron dosimetry techniques used throughout the world. ORNL health physicists influenced the setting of national and international radiation protection standards, called for the safe use of x rays and radioisotopes for medical diagnosis and treatment, and urged concern about exposure of uranium miners to radon gas.

In important ORNL experiments in 1956, bone marrow of mice and rats that had been damaged by exposure to whole-body irradiation was successfully replaced with marrow of healthy donors, suggesting that bone marrow transplants could be achieved in man to alleviate injury to the blood-forming cells from ionizing radiation.

In a long-term experiment begun in 1966, 30,000 mice were exposed to chronic doses of low-level radiation to determine if small doses of ionizing radiation increased the incidence of leukemia and cancer and shortened the life span of mice. It was found that below a certain radiation level, there is no statistically significant evidence of life shortening, but at or above that level, radiation induces specific tumors believed to shorten the life span of mice.

In 1962 ORNL biologists found that certain enzymes can repair radiation damage to cells caused by ultraviolet light; eight years later, they developed an assay for determining whether the enzyme that repairs radiation damage is present in human fetuses. To determine which chromosomes and genes are responsible for repairing DNA damage in cells exposed to ultraviolet light, biologists in the late 1970s used gene mapping techniques.



This mouse shows the effects of ENU, a powerful chemical mutant.

Chemicals and Health

In the mid-1960s ORNL biologists began studying the carcinogenic, genetic, and pathological effects of chemical agents such as gasoline fumes, pesticides, tobacco, and drugs. This work on chemical effects has been extended to studies of health effects of products of and effluents from the processes to convert coal to liquid and gaseous fuels and to extract oil from shale.

During the 1970s biologists at ORNL developed a number of simple assays for rapid screening for chemicals that induce gene mutations which can lead to cancer. These assays have shown that coal-derived chemicals are a greater health hazard than crude shale oil and petroleum-derived products. The route by which inert chemicals in coal are converted in the body to derivatives that cause mutations or cancer has been worked out at ORNL, and the responsible derivatives have been identified.

Another achievement of ORNL biologists, this one in the early 1970s, was the discovery that widely used pesticides and drugs can cause cancer in animals that are also fed nitrite, a food preservative. The chemicals react in the stomach to form nitrosamines, a class of highly carcinogenic chemicals. This research at ORNL, along with similar work elsewhere, has led to a significant reduction in the commercial use of nitrites as food preservatives.

ORNL's lung cancer research program produced an instrument for exposing laboratory rodents to cigarette smoke that is now widely used in studies of health effects of smoking. Significant findings from this program include: (1) nitrogen oxides, normally noncarcinogenic pollutants from automobile exhausts, markedly promote the development of lung cancers when a small amount of benzpyrene, a cigarette smoke carcinogen, is present and (2) an insufficient amount of vitamin A in the diet of rats may make the animals more susceptible to lung cancer, a finding that led to an international effort to define the potential role of vitamin A derivatives called retinoids as possible preventive agents in lung cancer. Researchers perfected a technique of transplanting the tracheas of laboratory rodents, a technique that now permits the delivery of precise doses of carcinogens to defined areas of the respiratory tract for study of initial changes leading to cancer.

Some chemicals are incapable of initiating cancers but can promote development of already initiated cancers. ORNL researchers are now working out the mechanisms by which such "tumor promoters" act, as well as identifying chemicals with this capacity. It has been found at ORNL that benzoyl peroxide, a chemical used in acne medications and cosmetics, promotes the growth of skin tumors in mice.

In chemical mutagenesis research, it was determined in 1971 that the drug hycanthone did not produce heritable mutations in mice, although it was found to be mutagenic in bacteria. On the basis of these tests, ORNL reported to the World Health Organization that it could not recommend the elimination of hycanthone, the drug used to combat the debilitating and sometimes deadly disease of schistosomiasis prevalent in less developed countries.

In 1979 biologists found that fertilized eggs in only some strains of mice are able to repair premutational lesions brought in by the sperm, which would otherwise lead to mutations in the offspring. Thus, male mice exposed to certain chemical mutagens and mated with females that have this special capability produce relatively fewer mutant offspring. The findings cast doubt on the interpretations made from certain earlier mutagenesis screening tests in mice in which the repair capacity of the female was unknown or the strain unspecified.

A "spot" test was developed to screen for chemicals that may cause mutations in mice. Embryos from a special hybridization are exposed to the test agent, and, if a mutation occurs in an early pigment cell, it will multiply as the embryo grows and form a clone of mutant cells. A chemical is presumed to be a mutagen if, upon administration to pregnant mothers, it results in an odd-colored spot in the fur of several offspring. The test, which saves time and money, is now used in laboratories throughout the world.

Environmental scientists found that some three-eyed and two-headed crickets hatched from eggs in sand contaminated with a coal-derived chemical. The "cricket test" is being investigated as a method for detecting chemicals in toxic contaminants that may cause birth defects.

Recently ORNL biologists found that ethylene oxide, an industrially important compound, causes chromosome damage in mice and that the laboratory chemical ENU (ethylnitrosourea) is the most effective mutagen ever tested in mice.

An ORNL researcher and student discuss enzyme changes in mice treated with chemical carcinogens.

A biologist specializing in macromolecular research works with laboratory models.

Basic Biology

ORNL basic research in biology has focused on the fundamental functions of living cells and on their responses to radiation, chemicals, freezing, and other environmental influences.

Using the ion exchange chromatography technique developed at ORNL for separating fission products, biologists in the 1940s separated and identified the basic constituents of the nucleic acids. This technique led to the concept that RNA and DNA, two distinct nucleic acids, have the same general structure, a finding that had a significant impact on biochemistry worldwide.

A milestone was achieved in molecular biology in 1956 with the discovery at ORNL of a unique species of RNA, later termed messenger RNA, which directs the order of assembly of amino acids into proteins in living cells. In 1964, techniques were developed for extracting from bacteria the large quantities of transfer RNAs needed to study how amino acids are assembled into proteins.

In 1962 ORNL biologists established that hormones such as cortisone act on cells by controlling the expression of specific genes, cellular elements that control transmission of hereditary traits and specify the structure of particular proteins that affect cellular function.

In 1966, studies on aging at ORNL showed that mice's defenses against disease become less efficient with age and that transplanted spleen cells from young mice rejuvenated the immune systems of old mice and lengthened their life span.

The first photographs of genes coding for ribosomal RNA precursor molecules (for synthesizing RNA) were taken at ORNL in 1968. In 1975 widespread recognition was given ORNL biologists for their electron micrographs showing the "string of beads" structure of chromatin—a structure which may affect the expression of genes.

In 1972 mouse embryos—removed from superovulated mother mice, frozen by slow cooling to −196 or −269°C, thawed by slow warming, and implanted in foster mothers—were successfully brought to term as normal, live, newborn mice. The technique is now being used in the United States and in Europe for preserving mutant strains of mice, and it has led to the use of frozen cattle embryos in livestock breeding. In 1976 ORNL, in collaboration with California researchers, showed that pancreases of fetal rats can be frozen to −196°C and yet, when thawed and implanted in diabetic adult rats, resume insulin production and reverse the diabetes of the hosts.

Since 1968 a new methodology called affinity labeling has been developed and applied to characterizing catalytic sites of enzymes, proteins that induce chemical reactions in human, animal, and plant cells. Because synthetic chemicals are designed to selectively inactivate key target enzymes by this technique, it was seen as a possible tool for developing drugs that exhibit minimal side effects and for increasing production of food crops.

At ORNL's satellite laboratory in Rockville, Maryland, a vaccine for the dangerous, debilitating disease known as hepatitis-B was developed in 1975.

Cancer, whether induced by agents such as radiation or chemical carcinogens or of natural origin, is thought to be a consequence of abnormal functioning of cellular genes. In the 1980s ORNL biologists began using recombinant DNA, or gene splicing, techniques to isolate and grow specific genes in quantities sufficient for detailed chemical analysis. These techniques help biologists understand how genes are normally "turned on" and how this expression is altered in the transition of cells to malignancy.

Recently, ORNL biochemists have deduced almost the entire structure of a virus known to induce cancers in mice and believed to represent an unusual expression of normal cellular genes, perhaps activated by a chemical carcinogen.

An ORNL technician uses remotely controlled manipulators in a hot cell to handle radioactive chemicals.

Isotopes and Nuclear Medicine

Oak Ridge's electromagnetic separators (calutrons), which were used to produce enriched uranium-235 during World War II, were converted early in ORNL's history to produce enriched stable isotopes of almost any element. When irradiated in an accelerator or reactor, enriched stable isotopes form useful quantities of high-purity radioisotopes. Today the largest single commercial end use for enriched isotopes is nuclear medicine.

Millions of heart patients have benefited from ORNL's calutrons, which constitute the free world's principal source of enriched thallium-203. This stable isotope, whose yield and purity have been increased recently by an ORNL development, is converted by American, European, and Japanese cyclotrons to radioactive thallium-201 for use in approximately three-quarters of a million heart scans annually. Physicians use radioactive thallium to "take a picture" of the heart to assess tissue damage following a heart attack or to identify potential heart attack victims.

Just as thallium concentrates in the heart muscle, other elements concentrate in specific parts of the body. Examples of other elements used in nuclear medicine that are produced by ORNL include radioactive calcium for bone scans, carbon-11-labeled compounds for identifying tumors and brain problems, and radioiodine for diagnosing and treating disorders of the thyroid. The calutrons also make isotopes used today in lasers and atomic clocks.

The first isotope to be obtained from reactor fission products at ORNL was plutonium-240, which was separated in gram quantities from uranium and fission products at the Graphite Reactor in 1943. By 1945, as plutonium production was transferred elsewhere, the Graphite Reactor was used to produce radioisotopes for medicine and industry. Working at the reactor two years later, ORNL researchers were the first to isolate technetium-99*m* in measurable quantities from fission wastes. Technetium-99*m* is now the most widely used radioisotope in clinical nuclear medicine. By neutron bombardment of substances placed in the reactor, scientists prepared radioisotopes such as tritium and phosphorus-32 for biological studies.

Carbon-14 produced in the Graphite Reactor was shipped to a St. Louis, Missouri, cancer hospital in August 1946, the first time that a reactor-produced radioisotope was transported to the private sector for use in nuclear medicine. In 1949 ORNL first produced cobalt-60 for cancer therapy to replace more costly radium. Five years later, cesium-137 was first separated from spent reactor fuel for use in cancer research and treatment.

By 1950 ORNL had completed 20,000 shipments of radioisotopes used for treating cancer, detecting childhood diseases, battling insect pests, and aiding the identification and diversion of oil and gasoline products in pipelines.

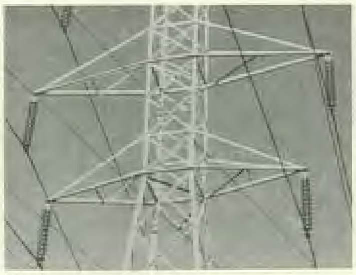
In 1961 methods for the separation of plutonium, americium, and curium isotopes were developed by ORNL. These isotopes are irradiated in the High Flux Isotope Reactor to form californium (used in nuclear medicine) and research amounts of other exotic elements used in ORNL's transuranic program. In the 1960s ORNL produced isotopes for auxiliary space power plants, including strontium-90 and curium-242.

In the first three decades of its history, ORNL developed the technology for producing radioisotopes used in industry, agriculture, research, space, and medicine. In the 1970s most of the technology was transferred to industry. Today ORNL still produces several radioisotopes used for nuclear medicine studies.

Recently, ORNL developed radioisotope-powered runway lights that can be used to guide U.S. military pilots flying in and out of foreign combat zones. The lights consist of phosphor pellets excited by beta rays (electrons) from tritium or krypton-85, which will be readily available when commercial nuclear fuel is reprocessed.

ORNL is currently producing and distributing radioactive osmium-191 from which the iridium-191*m* radioisotope is obtained and used for the evaluation of congenital heart disease in children.

ORNL also has recently developed new radiolabeled agents that are low in radioactivity but concentrate in the heart and brain long enough to provide clearer as well as safer images of these organs. One version of these agents will consist of stable tellurium and radioiodine and may well be used in the near future for characterizing heart disease or damage from heart attack as well as for detecting brain tumors and the occurrence of stroke.



Electricity:

Faithful Servant at the Flip of a Switch

By DON TRAUGER

To flip a switch and thereby be able to enjoy light, heat, television, and recorded music can be considered a miracle of modern life. Yet the flipping of switches is so commonplace that most people take electrical energy for granted. Perhaps the occurrence of an energy exposition in Knoxville marks a good time to reflect on the uses and sources of electricity.

I think first of electric lighting. I grew up in a home without electricity, so I am aware of the contrast between a coal-oil lamp and electric lighting, and I am grateful for the latter. The oil lamps may have cast a romantic candlelike glow, but they also smelled bad, occasionally smoked, gave poor light, and caused many tragic fires. You had to light the oil lamp with a match and then sit close to the lamps to read or write. It is wonderful to flip a switch and instantly have clean, safe, odorless light where you need it and at the desired level of intensity.

Besides providing for home comforts, electricity is essential today in the working world not only for traditional tasks such as manufacturing but also for the telecommunication equipment, computers, and associated devices necessary for high-speed processing and transfer of information. All of these benefits have come from electrical research and development work performed in the past 200 years by investigators in Denmark, England, France, Germany, Italy, Japan, and the United States.

Sources

Many sources of energy are used to generate electricity. Here in Tennessee, probably the best known source is hydroelectric power—generators used at the dams on the various Tennessee Valley Authority systems. In a hydroelectric plant, the pressure and momentum of water flowing from a pipe located at essentially the lowest level of the dam provide the driving force. This force is converted to mechanical energy when the water is directed against curved blades on a rotor. The energy required to meet the changing demand load for the electric generator is easily controlled by a valve that regulates water flow. Hydroelectric power supplies 12% of the nation's electricity.

About 48% of our electric energy is generated by burning coal to boil water at high temperatures and pressures to produce steam, which is discharged through a turbine. The steam is then condensed at the turbine outlet by cold water flowing in a heat exchanger, forming a vacuum on the discharge and allowing atmospheric pressure to be added to the pressure differential of the steam turbine.

It is this condensing step that heats cooling water taken from and released back into streams and rivers that has raised questions about damage to fish and other aquatic life. Instead of withdrawing water from streams by once-through cooling systems, many modern stations now use water-to-air heat exchangers or air-water mixtures in large cooling towers. These provide cooling for steam condensation and, in most cases, reduce the environmental impact. There are minor impacts, however; moisture from air-water heat exchangers has produced frost or even snow, and chemicals used to prevent corrosion may affect sensitive plant life. Since the cooling towers require energy for their operation, they also reduce plant efficiency.

Oil-fired and gas-fired power plants, which now provide 28% of U.S. electricity, work much like the coal plants. They are simpler to operate because it is easier to pipe in the liquid or gas to a burner than to handle the bulk coal. After World War II, American electric utilities, attracted to this simplicity, purchased many plants that burned oil and gas. In the 1970s, national

"Fusion energy today is at approximately the same stage of development as nuclear energy was before World II."

Don Trauger is ORNL's associate director for nuclear and engineering technologies.

concern for air pollution, more of a problem for coal than for oil and gas, led utilities to convert even more coal-burning plants to these convenient fuels.

Almost as soon as the utilities transferred fuel dependency for electric power generation to oil and gas, the Arab oil embargo of 1973 occurred, which brought home forcefully the extent of our reliance on the Middle East. After all, our national supplies of oil and gas are very limited compared with those of coal. Even more important, oil is uniquely suited as transportation fuel, and gas is extremely convenient for household heating and industrial as well as commercial uses. Because of rising prices of oil and gas and because it seems irresponsible to burn these limited fuels in power plants, the electric utility industry is slowly converting back to coal.

The newest source of energy for the production of electricity is nuclear power. The source of heat for generating steam to drive the turbine is uranium oxide fuel enriched with the fissioning isotope uranium-235. This nuclear fuel takes the form of a stack of small pellets in a rodlike container made of zirconium alloy (Zircaloy). The many rods are fitted into a square array called a fuel element, and many fuel elements are arranged to produce a nuclear "heater." The fuel elements are interspersed with neutron absorbers that can slow or stop the fission process. The absorbers are imbedded in a movable metal structure to provide nuclear plants with highly sensitive control of the nuclear reaction.

Present-day nuclear power plants, which generate about 11% of the nation's electricity, have high capital cost and are not designed for frequent changes in power output, but for base-load service. Where and when they are used, they supply at least part of the minimum load for the utility grid. Hydroelectric and fossil plants can provide the variable power to meet changing loads. Since nuclear fuel is less expensive than fossil fuels, this is the most cost-efficient way to operate a utility system.

Other energy sources well-publicized in recent years are wind, geothermal, and solar power and thermonuclear fusion. None of these currently produces a significant amount of energy in the United States, although geothermal power is of interest in a few places and wind power may be used in others. Geothermal energy is practical only where hot rocks exist near the earth's surface. Wind power, a form of solar energy, probably will be limited to a few localities where breezes are steady, severe storms infrequent, and visual impact unimportant.

Solar-electric technology is practical for satellites and other specialized uses but is too expensive now to be practical for use by utilities. The relatively low intensity of sunlight requires very large collection areas. Use of solar power for electricity production by utilities in a grid also would present serious problems since other plants would have to compensate when cloud cover and nighttime cut off the "source." Inasmuch as we have currently no effective way to store large amounts of electric energy, solar-electric power is not likely to be competitive in the near future. Solar energy, however, may well become attractive for space heating where energy storage is relatively easy. It could displace the space-heating use of fossil fuels, whether they are burned directly or used through the electric system.

Fusion energy today is at approximately the same stage of development as nuclear energy was before World War II. It is a more complex technology than nuclear fission and hence must be expected to take at least as long for its development. Extensive use of fusion-electric energy is probably at least 50 years from realization.

"Hydroelectric power supplies 12% of the nation's electricity."

Reliability

All utility companies, whether large or small, have transmission "tie" lines that connect to the grids of other utilities. In this way, a small company can still supply electrical power to its customers even if its single electrical generation plant is unavailable for months while a major repair or improvement is being made.

Utility companies understandably put availability of power to the customer as their highest priority. Like any company, utilities must satisfy customers. Consumers traditionally complain about the high utility bills, but they are even less tolerant of power outages. We would much prefer paying for this service to doing without it even for short periods of time. Fortunately, the electric utility industries of this country, most of Europe, and Japan are well equipped to maintain a high continuity of electric power. Multiple sources of electricity, interconnected grids, and dedicated service crews are the key to this success.

A major problem faced by utilities is providing electricity during peak power demands, such as at breakfast time or dinner time. One solution is "spinning reserve"—that is, having one or more generators spinning at full speed and ready to pick up a load in an instant. Spinning reserve is also needed to take up the slack when one or more generators or tie lines suddenly drop out of the supply, causing overloading of the remaining grid and possible shutdown by a large circuit breaker.

Utility companies having hydroelectric power available can use this source preferentially to accommodate to changing loads because it is easily started and stopped. Water not used is held until needed and, if used, does not add cost as would the burning of expensive fossil fuel. Naturally, a utility will use plants with low operating costs for the base load and bring on the more expensive units last. In order of preference today, base-load plant sources are hydroelectric (only when water might otherwise be wasted over the spillway), nuclear energy, coal, gas, and oil last, especially if the latter is imported. The quantity of hydroelectric power, however, seldom allows it to provide a very large part of the base load.

Utility companies sometimes use specialized machines to provide peak power—that is, to supply energy when the absolute maximum demand occurs for short periods, for example, during extremely cold or hot weather or in emergencies. Such machines often are turbine-electric systems driven by machines that resemble jet aircraft engines. They can be started quickly and stopped easily but are expensive to operate because they burn oil or gas and are not fuel efficient.

Use of intercompany tie lines requires close coordination among the companies. If the systems are not compatible, one company's load may cause another to shut down and an entire region could be without power. We have experienced this on a few occasions, most notably in the blackout of the Northeast in 1965. Many countries have just one electric utility, making the coordination of their overall grid easier.

A Closer Look at Nuclear Power

What about nuclear energy? Is it safe? Do we know what to do about nuclear waste? In my opinion, nuclear energy is a highly desirable source of electricity and is produced safely. Yes, we do know how to handle nuclear waste. Nuclear safety resides in the design of plants, a subject which has received attention at least equal to that for aircraft. Nuclear plants enjoy the benefit of

"Because of rising prices of oil and gas . . . the electric utility industry is slowly converting back to coal."

extensive backup systems and massive containment structures. The proof of nuclear safety is in experience. We now produce as much electricity from nuclear plants as was used by the entire country at the end of World War II. The accident record for employees is among the best for all industry, and no member of the public has ever been injured as the result of the operation of a nuclear plant.

Nuclear plants produce a very small quantity of highly radioactive materials, some of which are long lived. If all of the electric energy used by an average family of four for one year (including industrial uses) were produced by nuclear plants, the family's share of this processed waste would be the size of a small marble. If the wastes are placed in engineered storage facilities for a few decades to allow the most active components to decay and then are permanently stored in a deep geological formation, they should be very safe indeed.

I personally favor the use of salt beds in the arid West for ultimate disposal of radioactive wastes. These beds lie between 300 and 600 m (1000 and 2000 ft) below the earth's surface and have been undisturbed geologically for 200 million years. After about 5000 years of decay, the activity of the wastes will not exceed that of the original uranium ore, and they will be more effectively isolated from man than are ore deposits. Geological formations can be expected to store wastes for time periods that are considered well beyond what is thought adequate for safe storage. The pyramids of Egypt have stood for longer than the time required for safe isolation of nuclear wastes.

The larger volumes of low-level waste produced by nuclear plants decay over shorter periods—50 years, for example—so their storage is a smaller problem. The U.S. government and industry have not taken definitive steps to exploit the known technology of nuclear waste isolation, probably because such programs are difficult to justify economically until larger quantities of commercial waste exist.

I have already mentioned the existence of some environmental problems related to coal combustion and noted that gas and oil are relatively clean-burning fossil fuels. Potential major problems with continued long-term burning of fossil fuels are acid rain and the accumulation of carbon dioxide in the atmosphere. The latter could increase the retention of heat from the sun and cause a global warming that could have serious environmental impacts in the long term. Because coal contains a higher fraction of carbon and is a much more plentiful fuel, concern exists that a substantial increase in coal combustion may prove environmentally unacceptable. Thus, in the long run, nuclear energy—"fissile" rather than "fossil" fuels—may be the most attractive source of electricity.

The Bottom Line

The bottom line on this comparison of energy sources is that no one system can supply the entire solution to our continued need for energy. For reliability, it is best that electric utilities use several sources of energy. Coal piles can freeze, oil supplies from overseas can be interrupted, nuclear plants are subject to regulatory interruption, hydroelectric power is reduced by drought, and the other systems have limited potential. Thus, it seems desirable that each be used to best advantage; however, coal, nuclear energy, and hydroelectric power (in that order) seem most important for the near term. In the long term, it might well be that nuclear breeder reactors, coal, and hydro power will be the most important sources, in that order. To stretch

"If the plant can be located to deliver discarded heat to an industrial system . . . the . . . efficiency . . . can be as high as 60 to 80%."

these energy sources, governments and utilities are now encouraging consumers to practice conservation—to flip off the switch whenever lights and appliances are not needed.

In recent years, electric energy production has been criticized for being less efficient than other energy systems. There are grounds for that criticism, but the inefficiencies need not exist. In fact, in the period of cheap energy from the Great Depression to the early 1970s, there was little incentive to save energy. Gas, coal, and oil furnaces were notably inefficient, sending as much as 70% of the energy up the chimney. With improved controls, which operate the burners and the system more effectively, efficiencies can easily be increased from 30 to 70%. For electric systems, the improvements can be just as spectacular but may be more difficult to achieve.

In general, the end use for electricity has a very high efficiency; fluorescent lights, for example, provide good lighting with little heat, and electric heaters convert essentially all of the electric energy to heat. In general, motors are about 93% efficient in converting electrical to mechanical energy, but, with the design changes now being made, motors can easily achieve efficiencies of 97%.

The principal problem is in the efficiency of the electric generating plant. Modern plants that burn gas, oil, or clean coal and use cold running water to cool the condenser convert only about 38% of the fuel energy to electricity. Four percentage points (10%) of that is lost in transmission and distribution to the user, so the overall efficiency prior to end use is about 34%. For today's nuclear plants or coal plants with cooling towers and scrubbers, the overall efficiency of delivery drops to just over 30% or less. But even the most efficient plants throw 60% or more of their energy to the environment in the form of heat.

Many strides have been made to increase efficiency at the end use, for example, by heating homes with heat pumps. By using electric motors as the only practical driving force, the heat pump system extracts energy from the atmosphere to an extent that essentially compensates for the power station losses. Thus, the heat pump system can approach or even exceed the heat content of the fuel burned at the station to produce and deliver the electricity. A nice feature of the heat pump system is that it can cool the house in summer as readily as it heats it in winter. A thermostatic control will even automatically switch from heating to cooling as needed.

It is not necessary to lose 60 to 70% of the energy at the power plant. If the plant can be located to deliver discarded heat to an industrial system that can use it, the overall efficiency of the plant can be as high as 60 to 80%. This arrangement is called cogeneration because the plant generates both thermal and electrical energy. If one then uses heat pumps at the end use, the electric system efficiency can exceed that of any other. Europeans have widely used central heating systems for cities and are now using cogeneration to improve overall efficiency.

However we improve our national institutions with respect to energy, I am certain that electricity will continue to play an important role, particularly through the electrical control systems that improve efficiency and make life simpler and more comfortable. The electric system, even with all of its current sophistication, still offers opportunity for improvement. Perhaps through better understanding of our energy needs and opportunities from the 1982 World's Fair, we will begin to see the things we must do to use more effectively the energy resources at hand.

Based on accelerator studies, ORNL physicists came up with this model of the probable shape of the uranium-234 nucleus.

Basic Physical Research

Basic physical research is the foundation upon which new energy technologies are built. Experimentalists and theorists working together at ORNL have made important measurements and discoveries that have influenced physical science and technology throughout the world.

ORNL measurements in the 1940s confirmed that the radioactive nucleus xenon-135, which is produced by the fission process, has a strong tendency to absorb neutrons and thus "poisons" reactors by inhibiting chain reactions. Neutron capture probabilities of uranium isotopes were determined, leading to the conclusion that a large mass of natural uranium must be enriched significantly with uranium-235 to support a fast-neutron chain reaction.

In the earliest years of nuclear research, Nobel laureate Eugene Wigner and Alvin Weinberg, ORNL's director for 18 years, worked out a theory to design reactors that used ordinary water instead of heavy water for cooling. A water lattice experiment in 1948 showed that if the fuel were enriched to only a few percent of uranium-235, compact power reactors could be built that used forced-water cooling. This physical research laid the foundation for the widely deployed pressurized-water reactor.

In the 1950s ORNL physicists made important discoveries in the world of physical science. The half-life of a free neutron was measured in an experiment that confirmed that the neutron decays to a proton with radioactive beta emission. Also, physicists using the 160-cm (63-in.) cyclotron showed that fusion reactions involving nitrogen nuclei were infrequent, thus allaying fears that a hydrogen bomb explosion might set the earth's atmosphere on fire. ORNL designed the first isochronous cyclotron, which has been used to produce intense beams of protons at high energies.

Solid-state physicists in 1961 predicted theoretically the movement of energetic ions through a crystal's open regions, or channels. A study of channeling in 1963 showed that energetic ions aimed down channels in crystal lattices undergo less energy loss than those that enter in random directions—a phenomenon that gave information about the crystals themselves. In 1977 physicists discovered the "resonant coherent excitation effect," in which the electrons of ions channeled through thin gold and silver crystals become excited as they pass by rows of atoms in the crystal at just the right speed.

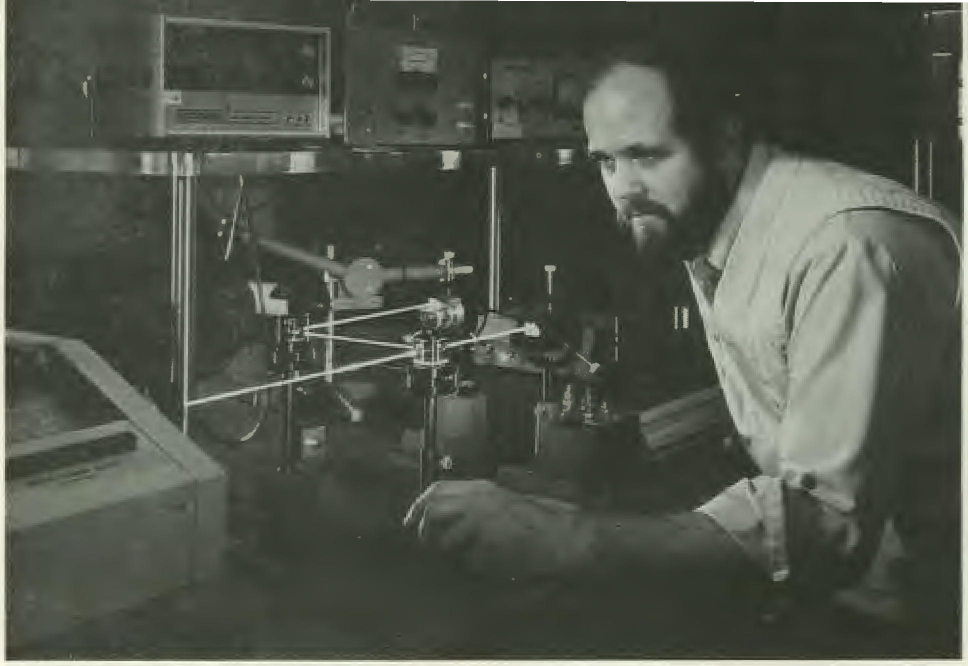
In the early 1960s ORNL researchers pioneered the development and application of germanium detectors, now manufactured commercially and used worldwide by nuclear physicists to measure gamma rays from excited nuclei.

In 1967 the intense neutron beams from the High Flux Isotope Reactor were used to study inelastic scattering of neutrons from metallic crystals by neutron diffraction. This technique was originally developed in the 1940s at ORNL's Graphite Reactor to study crystal structure and the nature of magnetism. Both small-angle x-ray and neutron cameras developed at ORNL have made important contributions to understanding the structure of physical and biological materials as well as structural changes that occur, for example, when plastic wrap is stretched, minerals form in teeth, and voids appear in irradiated reactor materials.

Experiments at the tandem Van de Graaff accelerator in 1971 showed that the uranium-234 nucleus is shaped like a football. Neutron beams of known energies from the Oak Ridge Electron Linear Accelerator were used to measure precisely the probability that fission will occur in uranium-235 and uranium-238.

In 1971 ORNL physicists discovered the giant quadrupole resonance, an excited nucleus that constantly changes shape and alternately resembles a ball, football, and pancake. In collaboration with a Netherlands laboratory in 1977, ORNL provided the first direct evidence of a giant monopole resonance, an excited nucleus that expands and contracts, changing in density but not shape. This discovery provides a measure of the compressibility of nuclear matter, which is a basic property needed to interpret collisions of heavy nuclei.

In 1979 physicists developed the new technique of laser-induced nuclear polarization (LINUP), which involves using a laser beam to line up extremely short-lived nuclei so that fission occurs preferentially in one direction. By determining the size of the frequency (energy) shift required in the laser beam to keep the nuclei and their fission fragments aligned along the beam, physicists can measure properties of these short-lived nuclear species, which until now have defied close examination.



An ORNL analytical chemist performs chemical analysis using a dual beam photoacoustic spectrometer.

Chemical Research

ORNL scientists discovered one of the world's natural elements and confirmed the existence of two man-made elements. Promethium, element 61, was discovered at ORNL in 1945 via an ion exchange chromatography technique pioneered at the Laboratory. The element was separated from fission products at the Graphite Reactor.

ORNL's Transuranium Research Laboratory was the home of 1973–1974 experiments that confirmed the existence of elements 104 and 105. Confirmation of the identity of element 104, a short-lived transuranium element previously discovered at Lawrence Berkeley Laboratory, was achieved by correlating the characteristic alpha particles of the new element with the characteristic x rays emitted by the element to which 104 decays.

In the 1940s ORNL applied neutron activation analysis techniques to detect and measure trace amounts of impurities in foods, drugs, metals, lubricants, plastics, and fertilizers. Later, charged particle activation analysis was developed and applied here. ORNL chemists discovered and developed the use of the ion exchange technique for separating radioactive metals essential to the nuclear industry.

The use of molecular beams in studying the mechanisms of chemical reactions was pioneered at ORNL in the mid-1950s. It was recognized that the details of gaseous chemical reactions could be better understood if the reactants could be brought together as crossed molecular beams. Molecular beam studies are now standard in major university laboratories throughout the world.

ORNL chemists developed an advanced form of filtration for desalting water in the 1960s. This led to the development of an industrial technique for removing pollutants and recovering valuable chemicals from wastewater.

In the 1960s chemists employed neutron diffraction, developed at ORNL, as well as x rays to probe the structure of liquid lead and bismuth and familiar molecules such as water and sugar. ORNL has been a world leader since the mid-1960s in photoelectron spectroscopy, a technique whereby photons from a light source such as synchrotron radiation are used to expel electrons from a target material. At ORNL this technique has been applied especially to studies of gases and is contributing to an understanding of chemical bonding.

Researchers used an ORNL-developed counter to measure short-lived radioactivity in lunar rocks brought back from the moon in 1969 by Apollo 11 astronauts. Finding a low ratio of potassium to uranium, they concluded that lunar rocks crystallized earlier than the oldest rocks found on earth.

In the mid-1970s, when lasers were being increasingly used as a research tool at ORNL, a laser scheme for one-atom detection was developed. Laser light of a preselected wavelength was used to knock loose electrons from a small number of atoms known to be present in a gas; a proportional counter counted the electrons, allowing determination of the number of atoms of one type existing in the sample. The technique promises to have applications in detecting rare events such as solar neutrinos and trace atoms of heavy metals present in pollutants.

As ORNL's energy interests broadened, chemists investigated the use of molten salts for fuel cells, thermal energy storage, catalysts to induce reactions for converting coal to liquid and gaseous fuels, and blanket coolants and material in fusion devices for breeding fusion fuel.

ORNL is the world's leading laboratory in studies of the chemistry of water under conditions of high temperature and pressure. Results of the research have been applied to understanding problems in steam generation in nuclear power plants and geothermal energy facilities.

ORNL analytical chemists developed a technique that uses x rays and aspirin to measure in construction materials microscopic amounts of asbestos, a health hazard. The U.S. government is considering adoption of the technique for determining whether precautions are needed to protect the public and workers from certain construction materials.

Coal chemistry at ORNL included a development in electron spin resonance spectroscopy, which allowed for the first time the study of the pyrolysis (thermal breakdown in the absence of air) of hydrocarbons that are models for coal. Nuclear magnetic resonance spectroscopy has been used at ORNL to obtain a "before" and "after" look to determine what happens to coal during reactions used in liquefaction. Chemists have studied substances present in coal—such as hydrogen and minerals that stimulate reactions—that could aid in the production of rich hydrocarbon fuels.

Measuring heat transfer in coal blocks is a step in determining the feasibility of in situ gasification.

ORNL has developed a prototype fluidized-bed system for burning high-sulfur coal to drive a gas turbine and produce electricity. The goal of the research is to make production of power from high-sulfur coal both economical and environmentally acceptable.

Coal Technology

The United States possesses one-fourth of the world's estimated coal reserves, so when the price of imported oil began to climb in the 1970s, the nation pursued environmentally acceptable methods of burning coal to produce electricity and converting coal to clean gaseous and liquid fuels.

Coal studies began at ORNL in 1971 when the Laboratory broadened its program to include nonnuclear energy sources and their impacts. In that year ORNL was asked to examine sulfur dioxide emissions from the Clifty Creek (Ohio) coal-fired power plant to see if something could be done to meet Ohio's new sulfur dioxide regulations.

One significant finding by the analytical chemists and biologists working together was that coal-derived oils are more biologically active (produce more animal tumors and cell mutations, for example) than are shale oil or petroleum crude oil, the latter being the least biologically active. They also found, after dividing the coal compounds into acidic, basic, and neutral fractions, that the basic and neutral fractions were largely responsible for biological activity. Analysis of products and effluents from coal conversion plants was done using the same methods by which ORNL identified the hazardous organic constituents of cigarette smoke, a research effort in support of the goal of developing a less hazardous cigarette.

To reduce the adverse environmental impacts of coal liquefaction plants, ORNL developed a tapered fluidized-bed bioreactor that reduces toxic phenols and other contaminants in waste streams to acceptable levels 40 times as fast as conventional biological systems.

In its search for efficient, clean methods of coal combustion, ORNL designed a model of a fluidized-bed coal burner and studied ways to improve its performance. By minimizing discharges of sulfur dioxide and nitrogen oxides, the fluidized-bed concept offers an environmentally acceptable way of burning coal for supplying process heat and electricity.

Coal cleaning by magnetic fields was developed into a commercial process by ORNL. The process separates out the high-energy carbon content of the coal from the materials that cause air pollution when burned—sulfur-bearing iron pyrites and ash. The former is weakly repelled by the magnetic field while the latter is weakly attracted to it, thus resulting in separation. This dry method is more economical than the float/sink separation process, which requires additional energy to remove water from the coal.

In the late 1970s ORNL developed acid leach methods of recovering aluminum, iron, and other metals from fly ash produced at coal-fired power plants. Similar leach methods, as well as magnetic beneficiation methods used for coal cleaning, are being studied for extraction of metals from eastern oil shales and coal conversion residues. Some of the metals are vital for the nation's industry and defense.

ORNL researchers identified the mechanisms by which the chlorine in coal concentrates in the fractionation columns of the H-Coal Plant in Kentucky and forms hydrochloric acid and other chlorine compounds that corrode liquefaction plant components. Their findings led to recommendations for alternative construction materials for future columns.

ORNL's Coal Liquids Flow System, which measures physical properties of process streams under operating conditions, has provided data that has influenced the development of major direct coal-liquefaction processes and design of synthetic fuel plants.

ORNL found a method for ranking coals by their ability to donate hydrogen to the process of coal liquefaction (turning coal to liquids). Because hydrogen is needed to convert the carbon in coal to energy-rich hydrocarbons, ORNL has studied several innovative ways of generating hydrogen, which can also be used for fueling aircraft and making fertilizer. One approach has focused on thermochemical reactions that could use waste heat from nuclear power plants to extract hydrogen from water. Another method aims at using sunlight and materials derived from green plants to split water into oxygen and hydrogen.

An ORNL researcher checks instruments in a simultaneous triple-ion-beam bombardment of stainless steel alloys. Accelerators are used in studies of radiation damage to a variety of materials.

Materials for Energy and Space Exploration

Materials research began at ORNL in the 1940s when Eugene Wigner, former ORNL research director who later was awarded a Nobel Prize in physics, predicted that radiation could damage reactor components enough to impair power plant operation. Since then, ORNL has developed into one of the world's largest materials research laboratories and is now known for developments of new structural materials that are resistant to high temperatures, chemical corrosion, neutron irradiation, and other stresses imposed by advanced energy systems.

In 1955 ORNL began developing improved nondestructive testing techniques to detect welding flaws in reactor components. These techniques, which measure the passage of x rays, electrical currents, or sound waves through materials, are still employed by the international nuclear industry.

A nickel-molybdenum-chromium alloy called Hastelloy-N was developed at ORNL in 1958 for use in the Molten Salt Reactor Experiment. Hastelloy-N, which is resistant to oxidation and corrosive attack by fluorides at high temperatures, is now manufactured by industry for use in components of jet aircraft engines.

In 1963 ORNL researchers discovered a mechanism to explain why metals subjected to high temperatures and low doses of slow neutrons become brittle. Embrittlement was traced to helium that is produced when neutrons interact with residual boron in nickel- or iron-based alloys.

In 1967 ORNL and British researchers observed that stainless steel swells under exposure to fast neutrons and becomes brittle when also subjected to high temperatures. These findings cast doubt on whether materials could withstand the elevated temperatures and high neutron fluxes of liquid-metal fast breeder reactors.

In 1968 metallurgists discovered that adding small amounts of dispersed titanium to stainless steel significantly reduces fast-neutron embrittlement. And in 1975 ORNL researchers discovered that adding silicon as well as titanium to type 316 stainless steel made the alloy even more resistant to neutron-induced swelling. This material, now being used to wrap fuel pins in a breeder component test facility, could make breeder reactors more economical by permitting a tighter core design and fewer fuel element loadings.

To test the durability of new reactor materials, ORNL was the first to bombard materials with accelerated particles to simulate quickly long-term radiation damage effects.

In solar energy research in the late 1970s, laser annealing was developed at ORNL for removing damage in silicon caused by ion implantation of boron. Phosphorus was introduced and uniformly distributed in silicon by neutron transmutation doping—using reactor neutrons to convert silicon-30 atoms to phosphorus-31 atoms. Both boron and phosphorus impurities must be present in silicon for sunlight to induce electricity in the semiconductor.

The newly developed techniques of ion implantation doping and pulsed-laser annealing are being used to make laser-diffused solar cells and to modify the near-surface properties of many types of materials. These surface modifications significantly affect such phenomena as friction, wear, corrosion, catalysis, superconductivity, and electronic properties of semiconductors.

In the late 1970s ORNL developed iridium spheres containing plutonium isotope fuel for thermoelectric generators to power the two Voyager space probes which recently flew by Jupiter and Saturn. Iridium-clad isotopic heat sources are now being developed for the European Space Agency's mission to study the sun.

Metallurgists developed a long-range-ordered alloy that is made of iron, nickel, cobalt, and vanadium and that increases in strength as the temperature rises. The alloy is surprisingly ductile—it stretches and bends easily without breaking—and may have potential use in high-temperature energy systems.

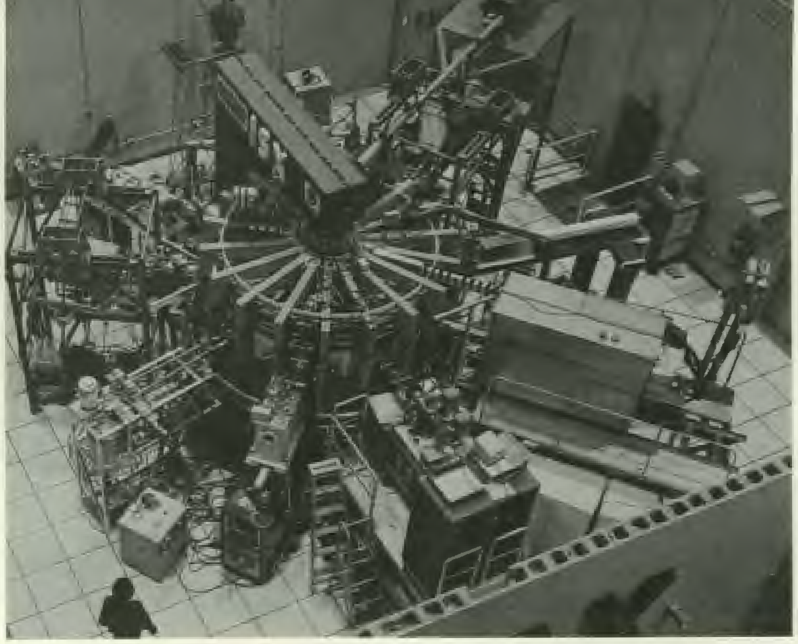
Recently at ORNL a high-chromium ferritic steel was developed for piping liquid metal in breeder reactors and corrosive coal liquids in coal liquefaction facilities. A better weld material for breeder reactors was also produced and tested.

Because they can withstand higher temperatures than metallic alloys, ceramics are being studied at ORNL as possible materials for highly efficient energy systems. Recently, ORNL researchers found that ion implantation toughens some ceramics. Ceramics alloyed with metal precipitates were developed for high-temperature solar absorber applications. A new wear-resistant ceramic material, developed at ORNL for machine tools and coal conversion plant components, is considered as tough as the best conventional tools made of cobalt-bonded tungsten carbide. The material—titanium diboride combined with nickel and chromium—has the advantage of not using cobalt, which is not always available for import.

This environmental test chamber simulates atmospheric conditions and pressures for studies of materials. Materials examined there include ORNL's long-range-ordered alloys that show increased ductility and strength at high temperatures.

This solar cell being tested for its efficiency in converting simulated sunlight into electricity was developed at ORNL using a new laser technique.

A view inside the ORMAK torus. This was one of the early tokamak experiments aimed at solving the physics problems of deriving vast quantities of energy from deuterium, an extremely abundant hydrogen isotope found in the ocean.



The Impurity Study Experiment has been used to study impurities from the fusion reactor wall that can cool the plasma fuel and reduce its efficiency. ISX has also achieved record beta levels.

Magnetic Fusion Energy

Thermonuclear fusion, which powers the sun and stars, could be an important energy source on earth if it could be controlled. To achieve fusion reactions in magnetic confinement devices, the plasma—a hot hydrogen gas made up of atomic nuclei and electrons—must be held together by magnetic fields long enough and must be heated hot enough (approaching 100 million degrees) that the nuclei overcome their electrical repulsion and combine. Theoretically, self-sustaining reactions of this type would release huge amounts of energy to make steam for producing electricity.

ORNL has studied fusion for the past 25 years and now has a broad fusion program, which contributes significantly to the development of the theory, experiment, and technology of fusion. Two types of magnetic confinement devices are being studied: (1) the tokamak, a doughnut-shaped machine modeled after the Russian device in which an intense ring current creates, heats, and confines the plasma and (2) the Elmo Bumpy Torus, a modified toroidal device invented at ORNL.

In 1970 ORNL built ORMAK, its first tokamak, and helped demonstrate the use of neutral atomic beam injectors to supplement the ring current's heating of the plasma, achieving temperatures of 20 million degrees. More recent tokamak studies in the Impurity Study Experiment (ISX-B) have focused on plasma impurity control, durability of reactor wall materials, magnetic field effects, various plasma heating techniques, pellet fueling, and beta elevation. Beta, a crude measure of the cost-effectiveness of fusion, is the ratio of the plasma pressure to the magnetic field pressure. In ISX-B, record beta levels have been achieved.

High beta is achieved in a fusion device when plasma pressure (temperature times density) is the highest possible for a given magnetic field strength without disrupting the plasma confined by that field. ORNL has raised plasma pressure by injection of neutral beams of hydrogen atoms to heat the plasma; injection of pellets of frozen hydrogen has been used to increase the density. Large-scale neutral beam injectors and pellet fueling techniques were pioneered in Oak Ridge.

ORNL neutral beam injectors have been used elsewhere to heat tokamak plasmas to record temperatures approaching 80 million degrees, five times the interior temperature of the sun. Systems derived from ORNL designs are now used in fusion devices in England, France, Germany, and Japan.

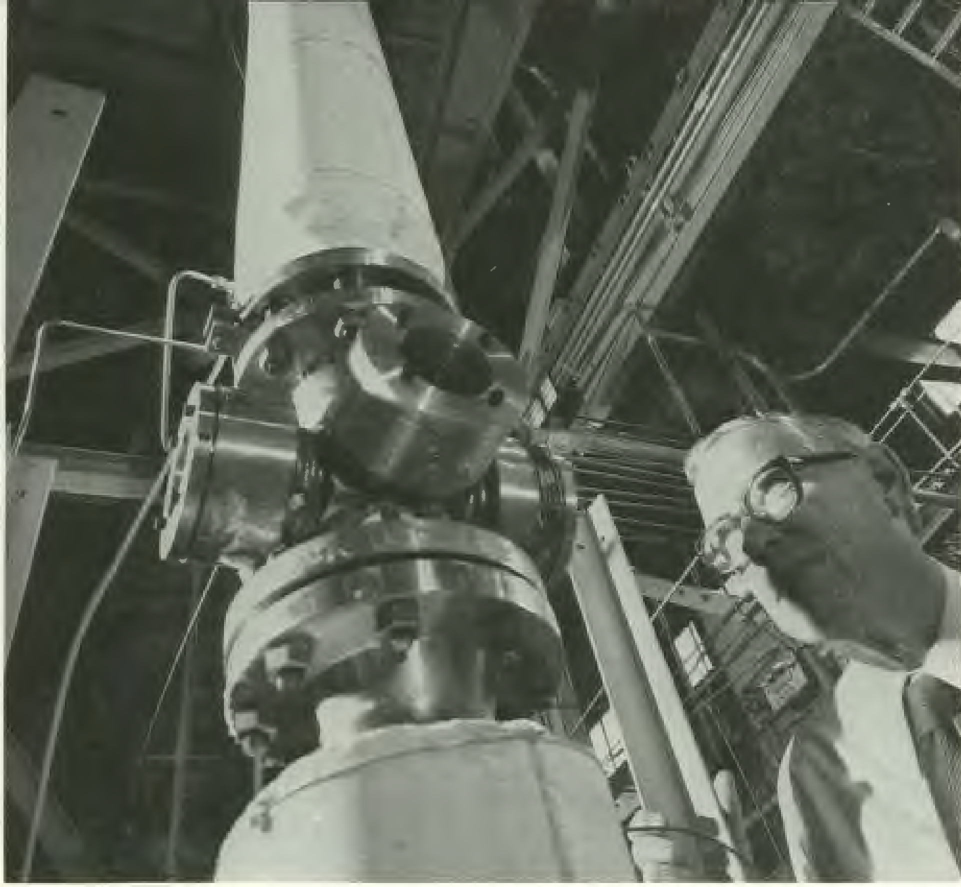
To make fusion reactors economical sources of energy, superconducting magnets are used rather than copper coils because superconductors are made from materials that offer no resistance to the flow of electrical current when they are chilled and thus require less energy. ORNL's Large Coil Test Facility will be used later this year to evaluate superconducting magnet coils designed and built by General Dynamics, General Electric, and Westinghouse in the United States as well as industries in Japan, Switzerland, and the European community.

In 1960 ORNL researchers demonstrated that a plasma with hot electrons can be surprisingly stable. This finding led to the concept of the Elmo Bumpy Torus (EBT), which is now a leading alternative to tokamak and mirror approaches to fusion energy in the United States. EBT is a toroidal magnetic trap in which microwave heating produces a steady-state plasma. In the present ORNL device, an electron temperature of 12 million degrees has been achieved. Japan has the only other EBT device. Unlike present tokamaks, which deliver their energy in pulses, the EBT can operate without interruption, making it a potentially more economic source of power. It has a simpler magnet configuration and is easier to maintain. ORNL is collaborating with industry in designing the more powerful EBT-P to be built in Oak Ridge in the late 1980s.

The Fusion Engineering Design Center has prepared a reference tokamak design for the Fusion Engineering Device (FED) that will test the engineering feasibility of magnetic fusion power. ORNL manages the design center, which is staffed from industry and national laboratories.

Information from ORNL's fusion technology and theoretical studies is shared with researchers all over the world. Many developments in fusion at ORNL have stemmed from information obtained through international exchange.

Answers for quiz on p. 10
1. f 2. e 3. g 4. b 5. d 6. c 7. a



ORNL researchers check the operation of a test assembly designed to calibrate instruments developed at ORNL for use in a German reactor safety experiment. The experiment is studying the movement of steam and water through a reactor during a loss-of-coolant accident when the emergency cooling system floods the overheating core with water.

Nuclear Safety

A nuclear reactor produces vast amounts of heat from the fission of enriched uranium in the fuel core. The core is flooded with water to prevent the fuel from overheating and to carry away heat to make steam for generating electricity. If the water flow to the core is interrupted by a pipe break, an emergency water supply system is activated to prevent a fuel meltdown that would result in a release of radioactive fission products to the environment. This is one of many measures to contain radioactivity.

Even though commercial reactors have many backup safety systems and an admirable safety record, research has been under way in the United States during the past 30 years to minimize the possibility of accidents and reactor-related health hazards and to lessen the consequences should any accidents occur.

In the mid-1950s ORNL conducted the first reactor safety experiments to determine which fission products escape in simulated meltdown accidents. By the following decade, charcoal bed adsorbers were developed at ORNL for removing a hazardous fission product, radioactive iodine, from reactor stack gas. In the early 1970s ORNL researchers cautioned the nuclear industry to pay closer attention to common mode failure, such as fire- or earthquake-caused damage to electrical cables that actuate safety systems.

During the Atomic Energy Commission's 1972 hearings on emergency core cooling, ORNL reported that zirconium embrittles significantly if subjected long enough to temperatures around 2300°F. As a result, the AEC lowered to 2200°F the calculated maximum cladding temperature allowed during a hypothetical loss-of-coolant accident and specified a limit to maximum allowable cladding oxidation, as well as requiring consideration of core geometry changes.

In 1977 ORNL data on steam oxidation of zirconium cladding and studies of heat transfer during experiments simulating loss of cooling suggested that criteria used for current pressurized-water reactors are either correct or conservative. The data from some experiments even suggest that it might be justifiable to allow higher reactor operating temperatures and thus increase electrical power output.

ORNL designed and tested reliable shipping casks and performed drop tests which showed that the casks used in commercial nuclear fuel shipments can withstand the most severe stresses posed by transportation accidents. To minimize the need for transportation, former ORNL Director Alvin Weinberg advocated the concept of nuclear power parks—clusters of power reactors and reprocessing plants at single sites. Power parks also have the advantage of concentrating experts and facilities in a few places.

In 1974 ORNL researchers found that deliberately flawed test reactor vessels burst only after being subjected to water pressures at least 2.2 times the design pressure. The same program also defined the problem of radiation-induced embrittlement in pressure vessels. Because brittle vessels are in danger of cracking if cooled too rapidly under high pressure (as during a loss-of-coolant accident), ORNL is working with government and nuclear industry on ways to avoid the potential thermal shock.

ORNL has developed advanced instruments to monitor reactor core reflooding for the International 3D Refill and Reflood Test Program. In this program, Japan, West Germany, and the United States are working on a closely coordinated set of experiments on the behavior of the emergency core coolant during loss of primary cooling.

In the past 15 years ORNL has led the way in noise analysis, a series of techniques for "listening" to patterns of signals from reactor cores to determine if they are operating normally or abnormally. In particular, following the March 1979 accident at the Three Mile Island nuclear power plant, ORNL teams were asked to check for loose parts and signs of core boiling using noise analysis. Other teams also helped minimize the release of radioactive gases to the surrounding population and set up procedures for postaccident cleanup operations.

Shortly after this accident, ORNL raised important questions about iodine chemistry, because the release of radioactive iodine was much less than expected at TMI. ORNL chemists found that iodine from water-cooled reactors combines with other fission products and remains in the water rather than escaping to the atmosphere. These findings have influenced nuclear safety research in the United States as well as in Canada, Great Britain, the Netherlands, and West Germany.

Reactor operators use a small crane to remove a fuel element from the High Flux Isotope Reactor.

Nuclear Energy Technology

From its beginning in 1943 until about ten years ago, ORNL has been largely a nuclear research laboratory, focusing first on the separation of plutonium and other radioisotopes from uranium fuel that had been irradiated in the Graphite Reactor. Later this mission was expanded to include reactor development.

In the late 1940s ORNL built a mockup of the Materials Test Reactor, which was later constructed by the U.S. Atomic Energy Commission in Idaho. The mockup evolved into the Low Intensity Test Reactor, ORNL's second reactor. The blue glow of Cerenkov radiation emanating from a reactor core submerged in water was first photographed at the LITR. These early swimming pool reactors became models for research reactors all over the world. Among these are the Oak Ridge Research Reactor (ORR) and the High Flux Isotope Reactor (HFIR), still operating as ORNL research tools. An early swimming pool reactor was exhibited by ORNL at the 1955 Atoms for Peace Conference in Geneva, Switzerland, and was the first nuclear reactor open to the public.

These early water-cooled reactors provided the technological base for the nuclear submarine program, which in turn provided the basis for the development of the pressurized-water reactors that constitute the bulk of the world's commercial nuclear power plants.

The nuclear submarine program also benefited from an ORNL process developed in the early 1950s for removing hafnium (a nuclear "poison") from zirconium, the standard fuel cladding material for light-water reactors. This process is still used throughout the world.

In the late 1940s and 1950s various shield designs and materials were tested at ORNL for use in nuclear-powered submarines and aircraft. ORNL shielding calculations guided the development of the radiation shield for Apollo spacecraft. In the late 1970s a radiation transport computer program now used throughout the world in reactor shielding analysis was developed, as were internationally recognized methods of radiation shielding analysis that have been applied to create safe and efficient shield designs for nuclear reactors.

Starting in 1949 ORNL became the world center for fluid-fuel reactor development. These reactors were intended either for propulsion or "breeding"—producing new fuel and power simultaneously. Milestones included Homogeneous Reactor Experiment I and II (in 1952 and 1957), both aqueous solution reactors, and the Aircraft Reactor Experiment (1954) and the Molten Salt Reactor Experiment (1965), both high-temperature molten salt reactors. The latter reactor operated successfully for several years, but the concept was abandoned in favor of the liquid-metal fast breeder reactor.

ORNL also had a prominent role in gas-cooled reactor development, starting in 1958 and continuing to the present. Work centered on the high-temperature gas-cooled reactor and has included evaluations, design studies, fuel and component development, and fuel reprocessing. In the 1960s ORNL developed the technology for making tiny spheres of nuclear fuel that show high performance and retention of fission products. This type of fuel is used extensively in gas-cooled reactors but can be used for other reactor types.

Research in support of the nation's liquid-metal fast breeder reactor (LMFBR) program was put into place at ORNL in 1968. ORNL contributed to component designs, materials development, a monitoring system, and development of a process to recover uranium and plutonium from the fuel. ORNL continues these research efforts in support of the Clinch River Breeder Reactor Plant, the nation's LMFBR project at Oak Ridge which aims to demonstrate the breeder concept of producing more fuel than is used while generating electricity.

In the 1960s ORNL became involved in nonnuclear research areas such as civil defense and nuclear desalination. The nuclear desalination program, for example, received international attention as a possible way of using nuclear energy to produce electricity and extract pure water from seawater and brines for agricultural uses. Large desalting plants have been built in the Middle East and elsewhere, but their energy source has been fossil fuels.

The underwater plasma torch and other remotely operated tools developed by ORNL were used in the 1970s to remove, cut up, and dismantle radioactive components of reactors whose service lifetime had expired. Technology based on ORNL developments will soon be used to dismantle Pennsylvania's Shippingport Reactor, which started operating in 1957 as the nation's first commercial nuclear power plant.

Nuclear Safety Information Center staff members abstract articles published in technical journals and prepare analyses based on the information they collect.

Information Services

Information is the primary product of Oak Ridge National Laboratory. Each year ORNL researchers publish numerous papers detailing research results and evaluating new information. In addition to producing new data, ORNL is also equipped to handle vast quantities of scientific and technical information available from sources all over the world. Because of computers and the availability of staff members versed in specialized subjects and information-handling skills, ORNL has successfully managed a growing store of data.

Since the Nuclear Data Project was established at the Laboratory in 1946, ORNL has been collecting, organizing, analyzing, synthesizing, digesting, and disseminating scientific information. Today ORNL has the most extensive complex of scientific data and information analysis centers in the United States.

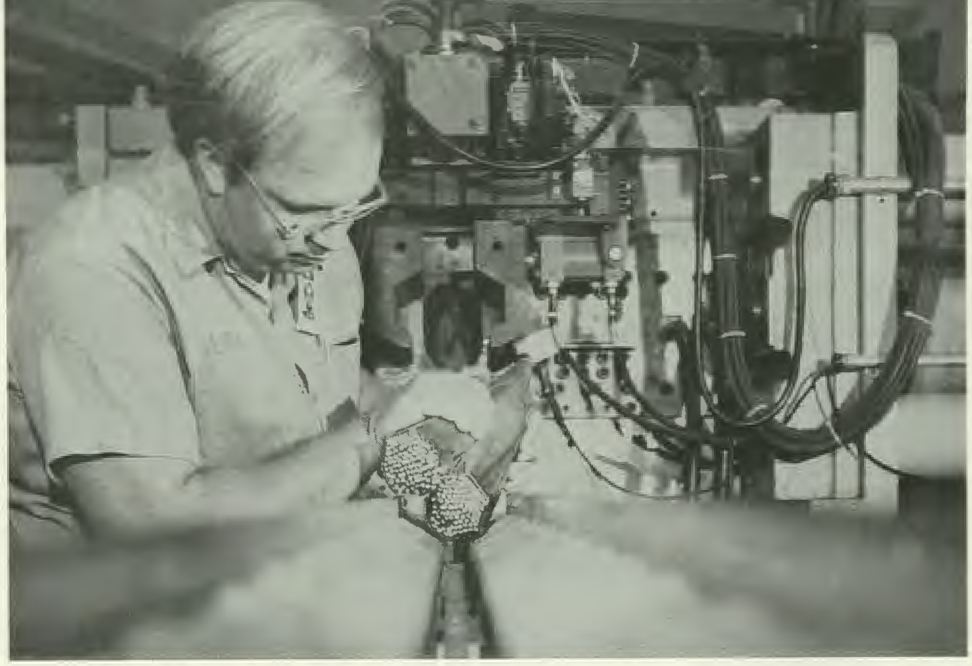
Information analysis centers began to proliferate at ORNL in the early 1960s, even before the 1963 recommendation by a panel of the President's Science Advisory Committee that specialized centers be created to systematically deal with the explosion of scientific information. The panel was headed by Alvin Weinberg, then director of ORNL.

At that time, ORNL had seven specialized information centers covering these areas: research materials, internal radiation doses, nuclear safety, radionuclides, radiation shielding, nuclear reactions of charged particles, and isotopes. These centers condensed, reviewed, and interpreted technical literature for the rest of the scientific community and, in some cases, made scientific assessments based on available data. Staff members of several information centers were responsible for compiling and editing technical progress review journals such as *Nuclear Safety*, which is still edited at ORNL.

Information centers at ORNL today specialize in such technical areas as environmental mutagens, environmental teratology (birth defects), toxicology, ecological sciences, chemical effects, hazardous materials, energy and environmental information, fossil energy, carbon dioxide, radiation shielding, nuclear safety, and energy safety.

ORNL information centers provide services to the Laboratory's researchers, program managers, and administrators. In fact, information centers have even stimulated new research at ORNL. For example, in the late 1970s, an information center brought to the attention of several ORNL physicists a Russian paper on laser processing of materials; as a result, these physicists went on to develop the technique of laser annealing for making efficient solar-electric cells.

ORNL's computerized information centers also develop new data bases and provide meaningful information to private industry, consumers, and government agencies on the health and environmental impacts of energy and related chemical technologies.



An ORNL technician prepares reactor subassembly for loading into the 250-ton shear for reprocessing nuclear fuel.

Nuclear Fuel Reprocessing and Waste Management

In nuclear power plants, heat for steam generation is obtained from the nuclear fission of enriched uranium. The nuclear fuel is considered spent when fission by-products make up about 5% of the fuel. Many of these fission products are highly radioactive, and in some the radiation remains intense for thousands of years. Consequently, these materials must be isolated from the environment. The remaining 95% of the spent fuel consists of recyclable uranium and plutonium; the latter is formed when uranium atoms capture neutrons liberated during the fission process.

The recovery of uranium and plutonium for reuse in new fuel elements can greatly reduce the quantity and complexity of fission product wastes for isolation while contributing substantially to the nation's energy supplies. ORNL has gained an international reputation as a center of expertise in nuclear fuel reprocessing technology by developing techniques for decontaminating and purifying fuel materials for recycle. The chop-leach process for preparing fuels for chemical reprocessing and the Purex process for decontaminating and purifying uranium and plutonium have become standard practices in the nuclear community worldwide.

Significant improvements to these processes are now under development for future application to spent breeder reactor fuels. In the breeder fuel cycle, the plutonium created by the breeding process represents a significant and renewable energy source. The REMOTEX concept, now under development at ORNL for advanced reprocessing, will allow recovery of this plutonium using totally remote methods that are expected to provide enhanced environmental protection, operator safety, and plant reliability.

ORNL chemical engineers have also made important contributions to the supply side of the present uranium fuel cycle. The solvent extraction processes developed before 1950 for recovery of uranium from ores, including the vast sandstone deposits in the western United States, have been used in mills throughout the world.

In addition, ORNL attracted worldwide attention in 1972 with the development of a two-step solvent extraction process for separating uranium from the phosphoric acid that is produced by the fertilizer industry from phospate rock. Uranium recovery from phosphates is now considered economically competitive with extraction from the western sandstone deposits.

The sol-gel technology is another ORNL development for the uranium fuel cycle. This technology may be used for fabricating new fuel elements, either from material recovered from spent fuel or from virgin uranium. Today it is being extended to provide a means for encapsulating nuclear wastes.

Today, most nuclear wastes from U.S. defense programs and commercial nuclear facilities are stored as liquid in underground tanks or as solids in water-cooled pools. The U.S. governmental policy, however, is to permanently isolate these radioactive wastes from the environment by encapsulation as a leach-resistant form within canisters that will be stored in a final repository. Studies are under way to identify suitable waste forms and geological repositories.

Of 11 waste form alternatives being studied for the U.S. government, ORNL has the lead role in developing two: (1) FUETAP concrete monoliths are formed from the combination of waste and additives at elevated temperature and pressure, and (2) coated ceramics are formed by sol-gel technology. The resultant spherical ceramic particles, composed of waste and additives, are coated with materials such as pyrolitic carbon.

ORNL has assisted the U.S. government in making choices for permanent, high-level radioactive waste repositories by studying salt, shale, basalt, and granite formations that are located deep inside the earth. The United States, France, and West Germany are now investigating the use of salt formations for permanent nuclear waste isolation. Much of what is known about the desirability of underground salt formations for this use was acquired by ORNL pilot studies in salt mines in the 1960s.

ORNL's pilot shale hydrofracture facility, which has operated successfully since 1960, has proved itself as a technically feasible method of sequestering nuclear wastes. In this facility, a liquid cement grout is mixed with radioactive wastes and pumped under high pressure to a depth of 300 m where the injected grout cracks the shale and solidifies in thin sheets between the strata. Today the facility is the only repository for permanent storage of intermediate-level nuclear wastes in the United States.

☆U.S. GOVERNMENT PRINTING OFFICE: 1982-546-067/21

Excerpt from Herman Postma's 1982 State of the Laboratory Address

"The user orientation of many of ORNL's programs is quite obviously a two-way street from which both users and we as hosts benefit substantially and which has an overriding benefit to the nation in making more efficient and productive use of the always limited resources for scientific and technological research.

"The user benefits from the opportunity to work at the frontier of his field with state-of-the-art equipment that would be difficult or impossible to duplicate. We as hosts gain the new insights and perspectives that come from working-level interactions with a broader segment of the technical community. Our sponsors benefit from the fuller utilization of the research capabilities in which they have invested and from the assurance that national laboratories have the skills required to build, operate, and manage such facilities in the national interest.

"Finally, there is the less tangible but no less important benefit in the improved integration of the overall scientific and technological enterprise in this country. This is a by-product of the creation of centers where the best talents in the academic, industrial, and governmental research communities can meet and work cooperatively to discover, innovate, and solve problems in areas so vital to the nation."

Answer to acrostic puzzle, p. 8

"When our economy used a million barrels a day, a strike in Texas of a 100,000-a-day field would rock the industry. But now we have an economy that uses seventeen million barrels a day. There are no bonanzas big enough to rock it." Adam Smith on the U.S. oil economy. (*Paper Money*, 1981)

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Ecologists on a hydraulic lift study deposition of coal fly ash on the leaves in an oak-hickory forest in ORNL's Walker Branch Watershed.