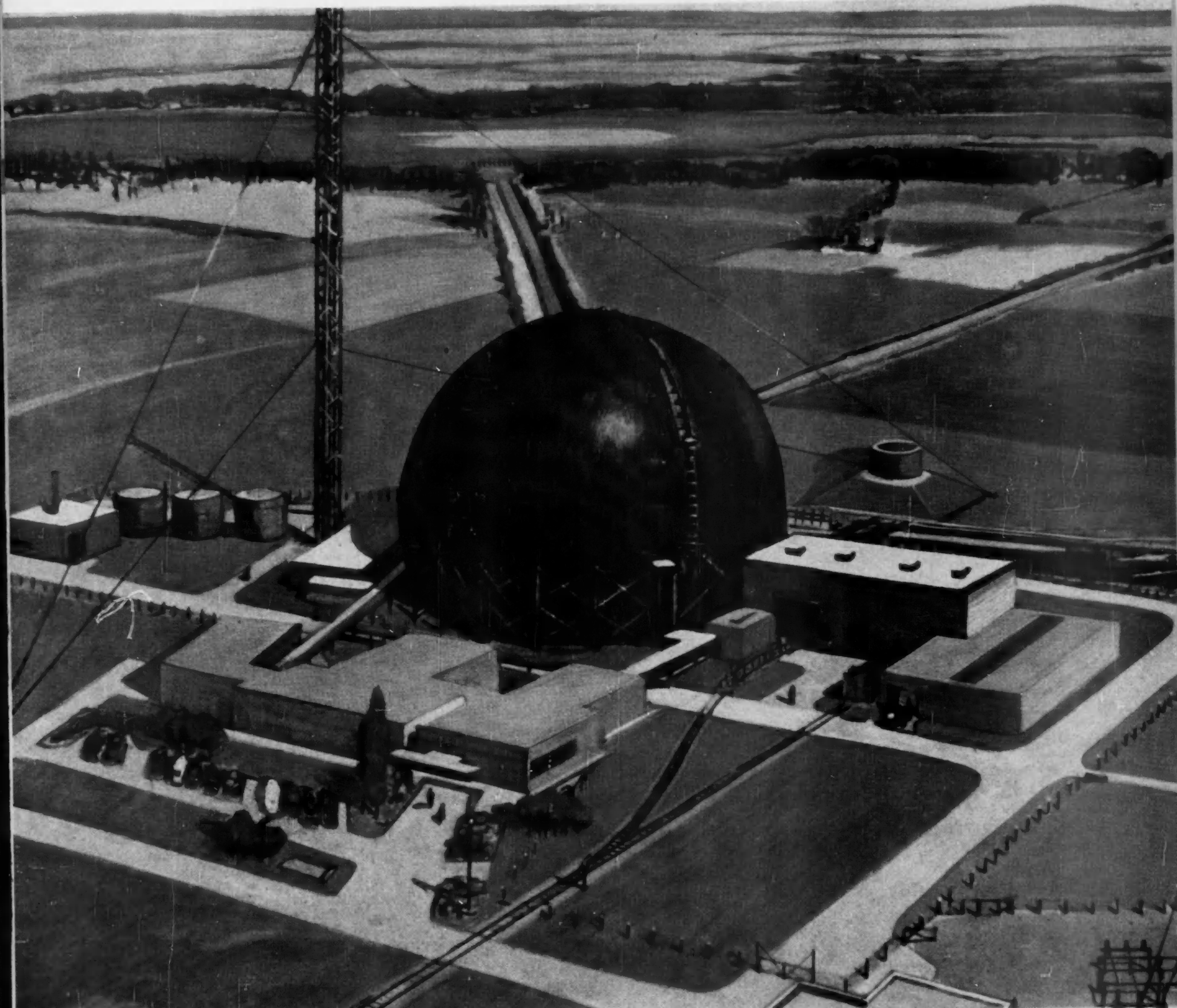
GENERAL ELECTRIC Review



Special Issue —

ATOMIC POWER FOR PEACE

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GENERAL ELECTRIC Review

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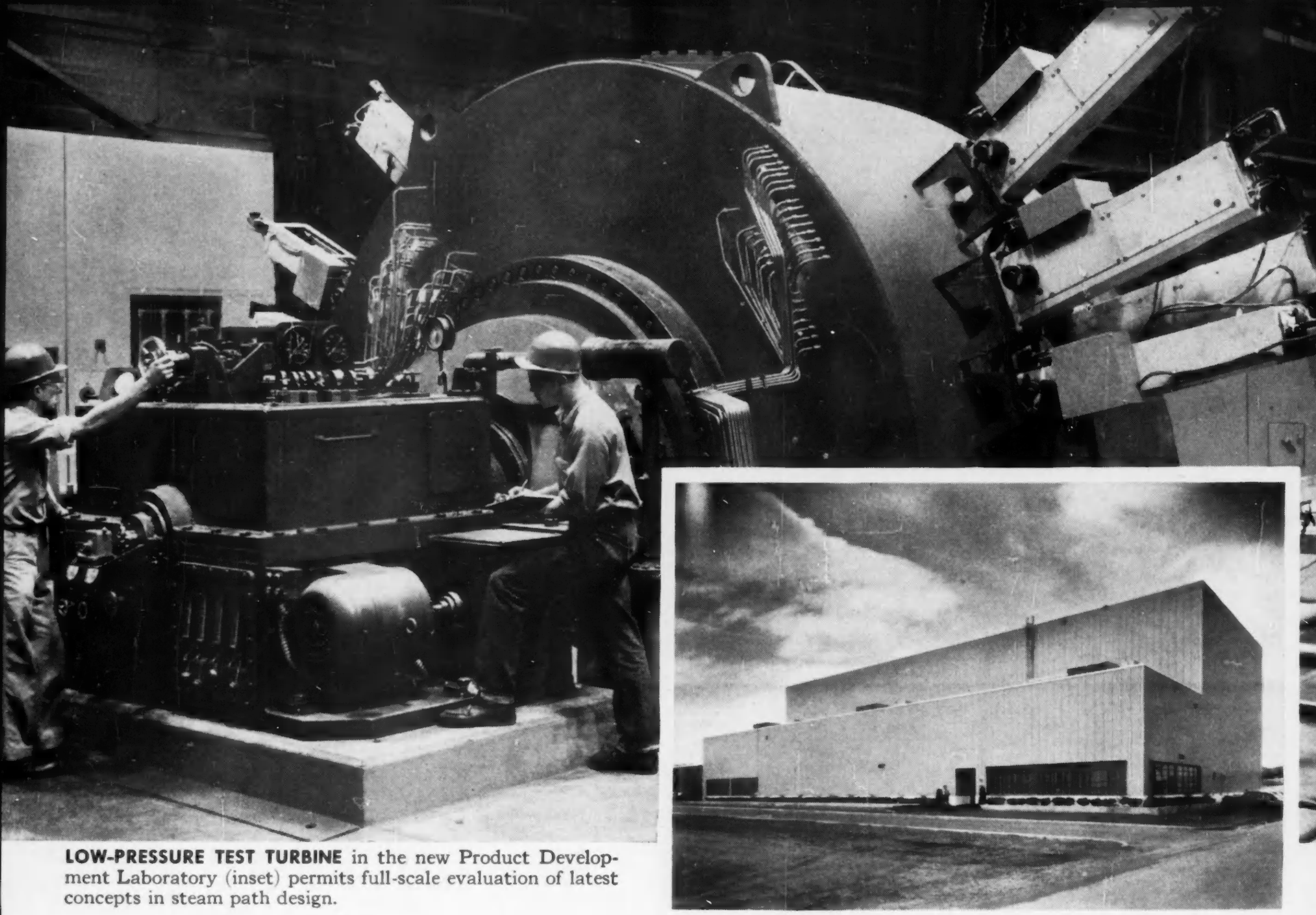
Atomic Power for Peace

COVER—An artist visualizes Commonwealth Edison's proposed nuclear power plant—largest of its type yet announced—that by 1960 will become a reality. The new plant, to be known as the Dresden Generating Station, will be built 47 miles southwest of Chicago at an estimated cost of $45 million and will contain GE's 180,000-kw dual-cycle reactor. For further details, see page 19.



LOW-PRESSURE TEST TURBINE in the new Product Development Laboratory (inset) permits full-scale evaluation of latest concepts in steam path design.

New turbine lab facilities ready to tackle the problems of nuclear power generation

The generation of low-pressure, low-temperature steam by nuclear power reactors re-focuses attention on the low-pressure section of steam turbines and the increased importance of efficient use of the energy in this region.

Present G-E low-pressure designs are basically suitable for application in nuclear power plants. Special problems, such as moisture removal to minimize later-stage erosion, need refinement.

The solution to such problems can be evaluated in the Turbine Development Laboratory's new full scale, low-pressure test turbine. The largest 3600-rpm steam parts built by General Electric can be run in this turbine under actual operating conditions.

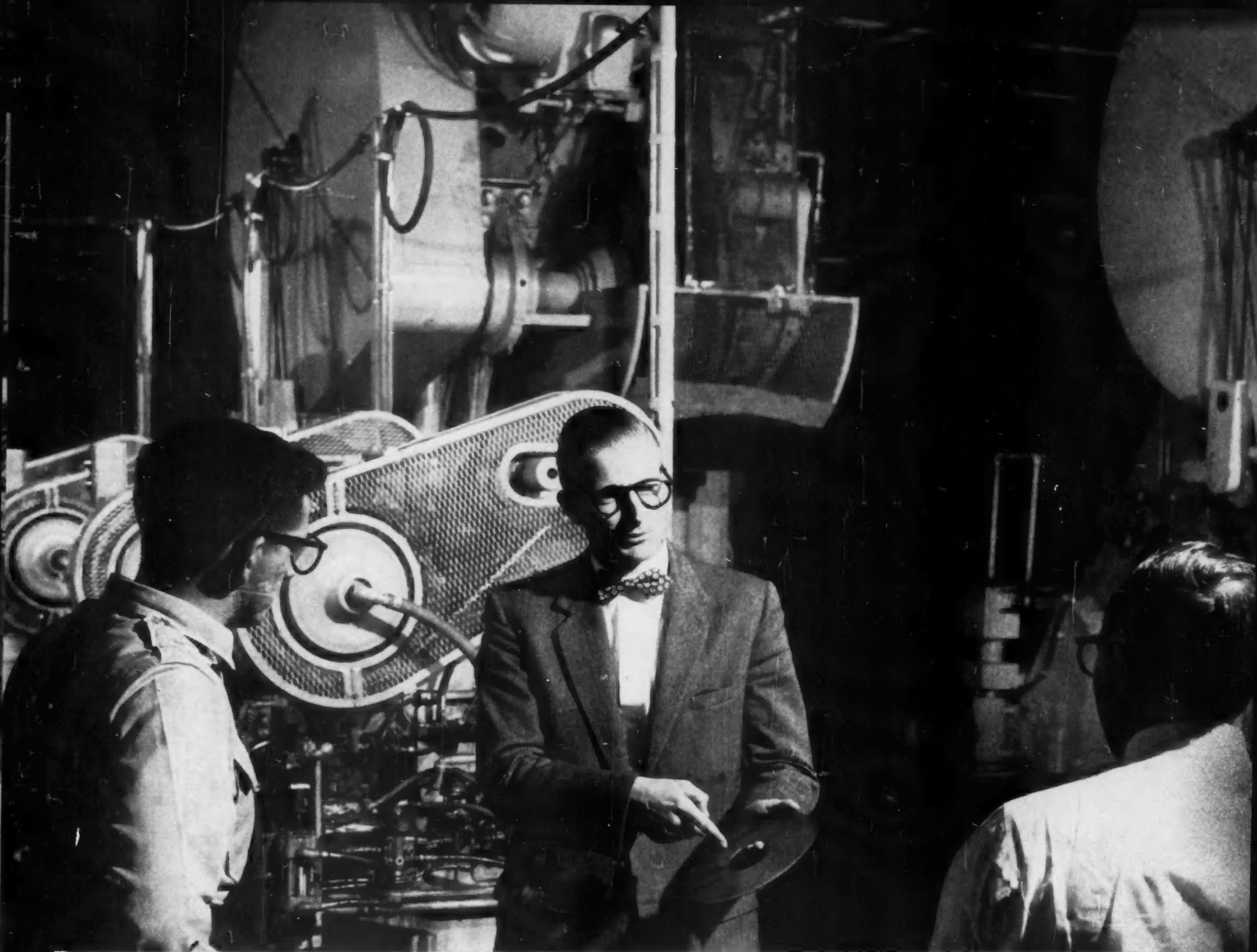
Other special problems such as corrosion of the turbine parts and contamination by radioactive steam are being tackled in General Electric's other complete laboratory and testing facilities. These and many other G-E programs are keeping turbine development abreast of trends in reactor design.

From America's first commercial generation of electricity by nuclear energy (using a G-E turbine)* to working closely with various study groups, General Electric is helping to make atomic-electric power an economic reality in the shortest possible time. General Electric Company, Schenectady 5, N. Y. 254-33

*At West Milton, N. Y., July 18, 1955

Progress Is Our Most Important Product

GENERAL ELECTRIC



THE ATOM—
AND THE WORLD WE LIVE IN

This has been called the Atomic Age. Its developments are based on knowledge which came to us from the scientists of many lands—from France, Italy, Germany, Belgium, Denmark, England, and from the scientists of our own United States.

That atomic knowledge reached the first practical peak in its progress when, under the stands at Stagg Field at the University of Chicago, in the Argonne Laboratory, Enrico Fermi said at 3:53 o'clock on the afternoon of December 2, 1942: "The reaction is self-sustaining." Fermi was speaking from the threshold of the first low-power atomic pile ever operated in which nuclear fission was produced and controlled.

At that time the world was enmeshed in a terrible war—World War II. Fermi's historic statement opened a new door. The great power and know-how of American Industry were pressed into service. Engineers were called on to build upon the new foundations established by the scientists. Each of us had his assignment. I used to say two prayers at night—one that we would succeed, one that we would not. Then came Hiroshima and Nagasaki. The world stood still. And World War II came to an end.

Out of the ruin and ashes of World War II came the vision and the conviction to put this new-found power to work—but to put it to work for peace. At the ground-breaking ceremonies at Shippingport, near Pittsburgh, on Labor Day, 1954, Admiral Strauss, Chairman of the Atomic Energy Commission, said " . . . government enterprise joins with private industry in a project where men of friendly nations can come to study and perceive and learn from us. . . . "

And the Honorable Sterling Cole, then Chairman of the Joint Congressional Commitee on Atomic Energy, said " . . . this is a day of fulfillment. It is the end of the beginning. May it make the world more like the design of the Architect of the Universe. . . ."

Then on the television screen we saw President Eisenhower wave a neutron wand in Denver, and immediately we heard the start of an automatic power shovel. We saw the shovel, without human hands to guide it, move into the clearing before us, dig its jaw down into the ground, and throw into the air the first shovelful of dirt for America's first full-scale atomic power plant for peace.

That was a historic moment—a thoughtful moment—a reverent moment.

Today, President Eisenhower is pressing his plan for making atomic power available for peaceful uses to those nations friendly to the proposed programs. The purpose of these programs is to spark the creative and inventive skills latent in the free world—pool them and put them to work for the betterment of the conditions under which men must live.

At West Milton, near Schenectady, NY, on July 18, 1955, Admiral Strauss, Chairman of the Atomic Energy Commission, closed a switch, and through joint effort by the Government and General Electric, engineers for the first time provided electricity, generated from an atomic source, to be commercially distributed through transmission lines going across the countryside, for immediate use in America's homes, farms, and industries.

The people in the adjoining villages were excitedly pleased. One mother said: "I think it's wonderful. When our three children go back to school in the fall and are asked what happened this summer, they will have plenty to talk about." Another mother said: "It's very interesting. I'm very excited. It's something we'll be able to tell our children and grandchildren."

Just three days after the West Milton ceremony, the submarine *Seawolf* was launched and christened at Groton, Conn. Powered with an atomic reactor of the type used at West Milton, the *Seawolf* contains a nuclear power plant of different design than any used before in submarine propulsion. The switch that Admiral Strauss closed at West Milton was a double-throw switch. With it, he might just as easily have diverted power to the propeller shaft of a military weapon. May we never have to throw the switch that way, even though protective weapons still have to be produced and maintained.

President Eisenhower has said: "Out of the use of this new and great energy source, along with boundless opportunities, come new and great human problems that require new and great solutions produced by broadly informed, wisely sympathetic, spiritually inspired minds."

In this age in which we live, people everywhere are looking to the engineers and the scientists to make sure that the advances of atomic power will not be full of frightful surprises, but rather will be applied to useful purposes to bring understanding, happiness, and good will to the world we live in.

EDITOR

FOR YOUR REFERENCE: A LIST OF NUCLEAR TERMS . . .

ALPHA PARTICLES—Helium nuclei containing two neutrons and two protons. They have great ionizing power but very little penetrating power and are dangerous to living tissues.

ATOM—Chemically, the smallest electrically neutral constituent part of an element that can take part in a chemical reaction. Physically, it consists of a positively charged nucleus surrounded by a compensating number of negative electrons in various orbits.

ATOMIC POWER—Power, or energy, released in nuclear reactions.

BETA PARTICLES—High-speed electrons that travel several feet in air and are dangerous to living tissues.

BREEDING—The process whereby a fissionable species is utilized as a source of neutrons to produce more nuclei of its own kind than are used up. This is the function of a breeder reactor.

CAPTURE—A process in which a nucleus acquires an additional particle.

CHAIN REACTION—As applied to a nuclear reaction, one in which neutrons essential to the reaction are produced by the reaction in sufficient quantity to sustain or increase the reaction rate.

CONVERTING—The process whereby neutrons are used to transmute thorium-232 into uranium-233 or uranium-238 into plutonium-239. Less specific than breeding.

CRITICAL MASS OR SIZE—The mass of nuclear fuel for which a chain reaction proceeds at a constant power level. This is related, among other things, to the volume it occupies, or size.

CURIE—The number of disintegrations per second from a gram of radium (3.7×10^{10}), used as a unit of radioactivity.

DEPLETED URANIUM—Uranium having less than the natural content, namely 0.7 percent, of the easily fissionable uranium-235.

ELECTRONS—The negatively charged particles surrounding an atomic nucleus to form an atom. Each electron has 1/1840 the mass of a light hydrogen atom.

FISSION, ATOMIC—The splitting of the nucleus of a heavy atom, as uranium or plutonium, into nuclei of lighter atoms—the fission products.

FISSION PRODUCTS—Elements that result from atomic fission. In addition to uranium and plutonium, these may consist of more than 40 different radioactive elements—barium, iodine, cerium, arsenic, silver, tin, cadmium, and others.

FUSION, ATOMIC—The joining of nuclei of light atoms, as deuterium, into a nucleus of a heavier atom, as helium.

GAMMA RADIATION—High-energy electromagnetic radiation that has tremendous penetrating power and is dangerous to living tissues.

HALF-LIFE—The length of time it takes a radioactive element to decay to the point where one half of the original material remains.

HEAVY WATER—Water in which the hydrogen of the water molecule consists entirely of the heavy hydrogen isotope of mass two. It is used as a moderator in certain types of nuclear reactors.

ISOTOPES—Atoms with the same atomic number, that is, the same number of protons in the nucleus but different atomic weights because they have different numbers of neutrons in their nuclei. Thus uranium occurring naturally as ore consists of three isotopes, U-234, U-235, and U-238, with the U-234 and U-235 making up less than one percent of the total mass.

MODERATOR—A substance, such as graphite or heavy water, used in a reactor to slow down neutrons from the high energies at which they are released in fission to lower energies at which they cause fission more readily.

NUCLEAR ENERGY—See atomic power.

NEUTRON FLUX—A term used to express the intensity of neutron radiation, usually used in connection with the operation of a reactor.

NEUTRONS—Electrically neutral components of atomic nuclei. Neutron radiation is highly penetrating. Free neutrons are often classified according to their speed or temperature, as thermal, slow, intermediate, and fast.

NEUTRON CROSS SECTION—A measure of the ability of a material to interact with neutrons by scattering, capturing, or being fissioned by them.

NUCLEUS—The positively charged core of an atom that contains the major portion of its mass. Its diameter is about 1/10,000 of the diameter of the atom.

PLUTONIUM (Pu)—A fissionable element of atomic number 94. Its isotope of mass 239 is the result of the capture of a neutron by U-238.

PROTON—The nucleus of ordinary light hydrogen and a constituent of all nuclei.

RADIOACTIVITY—Phenomenon of emission by unstable nuclei of particles or electromagnetic waves, as alpha, beta, or gamma radiation.

REACTOR, ATOMIC—A device designed to maintain a controlled nuclear chain reaction.

ROENTGEN—The absolute unit of x- or gamma-ray dosage used for measuring radiation exposure.

THORIUM (Th)—A natural radioactive element that can be transmuted into uranium isotope U-233 for use as fissionable material.

TRANSMUTATION—The process whereby an atomic nucleus of one species changes into one of a different species, often accomplished by bombardment with nuclear particles, as in a cyclotron or nuclear reactor.

URANIUM (U)—A natural radioactive element, consisting mainly of the U-238 isotope, with less than one percent of U-235 and U-234.

. . . AND OPERATIONAL ABBREVIATIONS

AEC—The United States Atomic Energy Commission, established by Congress, August 1, 1946.

ANP—The Aircraft Nuclear Propulsion Department, Evendale, Ohio, of General Electric's Atomic Products Division, operated by GE for the AEC and the Air Force.

HAPO—The Hanford Atomic Products Operation, Richland, Wash., of GE's Atomic Products Division, operated by GE for the AEC.

KAPL—The Knolls Atomic Power Laboratory, located near Schenectady, NY, of GE's Atomic Products Division, operated by GE for the AEC.

Atomic Power—A Challenge to U.S. Leadership

By FRANCIS K. McCUNE

For nearly a decade, most of the world has been watching from the sidelines as the scientists and engineers of the communist and free worlds race for superiority in atomic weapons. Not purely a spectator sport, at times the game has threatened to engulf and destroy all the people on both sides. The natural interest in the contest has blinded many people to another struggle that is emerging—the international race for pre-eminence in the development of atomic power for peace.

Do any of us adequately realize the implications of this race? We stand at a point in history that could aptly be described by Shakespeare's familiar passage from *Julius Caesar* . . .

"There is a tide in the affairs of men,
Which, taken at the flood, leads on to fortune;
Omitted, all the voyage of their life
Is bound in shallows and in miseries.
On such a full sea are we now afloat;
And we must take the current when it serves,
Or lose our ventures."

Seventy-five years ago, pioneers of the Electrical Age experienced relatively similar relationships to those of the Atomic Age. And the bold, imaginative plans they made changed the course of history and affected the lives of everyone who uses electric lights or power or who has products made with power-driven tools in electrically lighted factories. History has repeatedly taught us in the electrical industry to reach boldly for seemingly impossible long-range goals.

Urgency characterizes the development of peacetime atomic power with all the participants aware of the high stakes.

Atomic power offers the "have not" areas—Asia, Africa, and most of the globe—the hope of a way out of the old prison of poverty and industrial backwardness that their lack of energy sources and industrial development has placed them in.

In England and Europe it offers a second chance—an opportunity to regain the industrial leadership that they enjoyed before the great World Wars.

Russian leadership in atomic power would be a long-range instrument for economic leadership and political dominance. Communism plus atomic power might yet convert the world where communism alone has failed. It offers, too, another way of offsetting the unmatchable lead of the U.S. in the production of electric power.

In the United States, atomic power challenges our leadership. It provides another opportunity to prove that freedom and private competitive enterprise are the best and quickest ways to obtain the benefits of great technological advances.

One of Russia's most potent weapons may prove to be the ability to hold out the promise of atomic fuels and know-how to other areas of the world.

Let's make no mistake about the nature of the race. The struggle is still between freedom and slavery, between the supremacy of the state and the individual. Our national existence and the future of the free world depend on the successful defense of our concepts and way of life, whether they are challenged by acts of violence or bribery. Failure here spells disaster.

Already the contest is on. Great Britain has committed herself to build 12 power stations run by nuclear energy. In 10 years, according to the plan, new nuclear stations will constitute one fourth of the growth factor demanded annually by Britain's expanding industry and population, and in 20 years they may be building only nuclear generating equipment.

Russia has one 5000-kw atomic plant running. And the Soviet plans to triple the output of its electric power system in the next decade. Generation of electric power, totaling 142,500,000,000 kw-hr in 1954, should thus rise to a level between 427,500,000,000 and 570,000,000,000 kw-hr.

Other nations, lacking our resources in the weapons field, have concentrated on the peaceful uses for the atom. In fact, 12 European countries have already formed a pool for atomic research and are building a laboratory in Switzerland.

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Mr. McCune is Vice President and General Manager of the Atomic Products Division, General Electric Company.

What is the United States present position? Although too early to predict a definite pattern, we have some advantages . . .

- The United States has the most extensive experience and the largest capital plant in the field of nuclear energy. Though most of this is government contract work with military purposes, American industry has supplied most of the talent, the skilled technical and managerial manpower, and much of the know-how.
- America has the largest experience in the design and operation of power facilities.
- In the system of private competitive enterprise, the United States has a proved and unrivalled instrument for progress through technological development. We can preserve or increase our lead by relying on the peculiar advantages of the American economic system—incentive and individual enterprise.

Many of the nations with whom we are competing are poor—poor in energy sources. Contrast this to our abundance of low-cost electric power. And our wonderfully productive coal, oil, and gas industries can continue to supply all our energy needs for a long time to come.

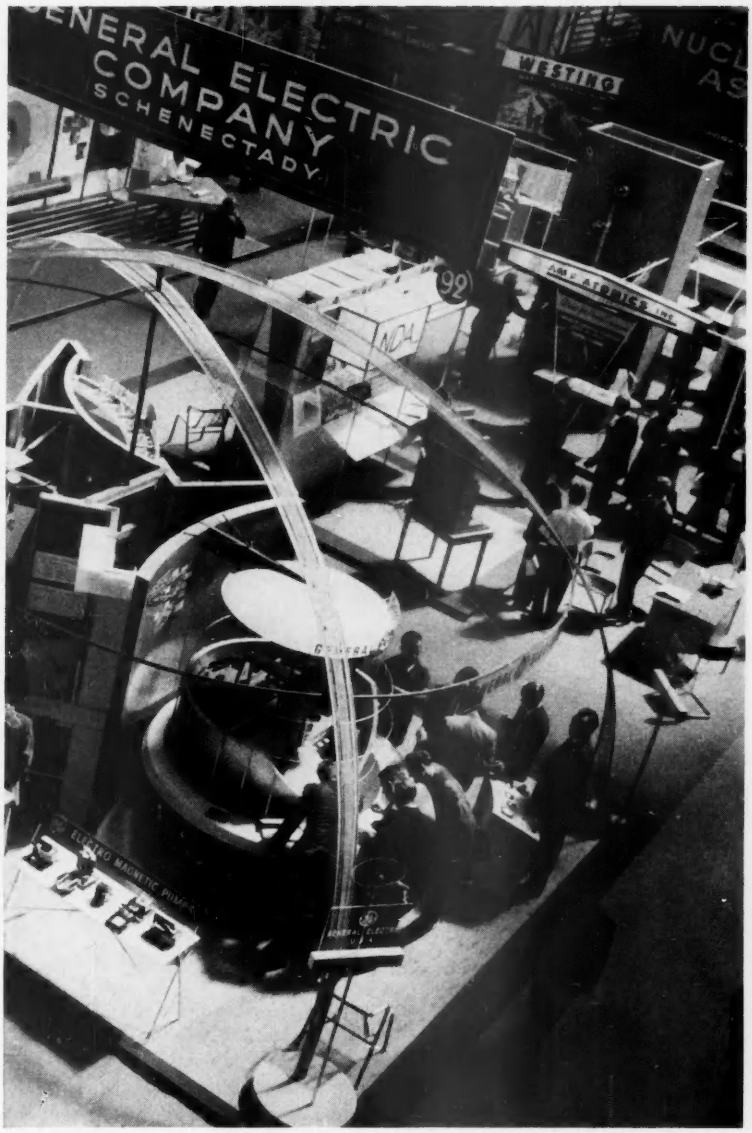
Thus our decision is harder. But the ability to use foresight in making hard decisions proves the vitality of nations. Further, it is good business management to balance the short-term goals against long-range objectives. It has been suggested that the period of planning should be at least 20 years, and in the atomic energy business, 50-year plans are not unrealistic.

No one conscious of the business realities of the atomic energy industry will enter the field lightly or without extensive planning.

We have witnessed, some even participating in, the first decade of the atomic era. Looking forward, what can be seen? Three great economic realities shape our times and will change all our lives within the next 20 years . . .

- Our population will reach 200 million by 1975.
- Our need for electric energy will reach two-trillion kilowatt-hours by 1975.

REFLECTIONS ON GENEVA . . .



THE COMMERCIAL EXHIBITS AT GENEVA REPRESENTED WORLD-WIDE INDUSTRIES.

Mr. McCune represented General Electric at the recent International Conference on Peaceful Uses of Atomic Energy sponsored by the United Nations at Geneva, Switzerland. You will be interested in some of his observations . . .

At Geneva it was evident that the great strides made in the atomic field have opened the doors to a wide, expanding source of power that may be used to promote the welfare of mankind. I feel, as I am sure the others involved also feel, that this United Nations Conference succeeded beyond all expectations.

This success manifested itself in the general attitude that prevailed among the delegates. Attendence was excellent, and the healthy exchange of information characteristic of the Conference has helped immensely to fortify the channels of scientific and commercial communication between countries. As a result of this exchange, information has been made available that will allow many countries to re-examine their plans for future power programs. Therefore, this Conference may well serve as a medium for encouraging and hastening the use of atomic energy for power generation throughout the world.

For those of us in America with commercial interests, one benefit of the Conference was the focusing of attention on the approach of other countries to the sale of equipment and the exchange of information. By studying this approach, we can determine the obstacles that face us in respect to world-scale trade and then team up to meet them.

Skill in the arrangement of scientific material, excellent program organization, and the co-operation of the delegates all aided in making the Conference a success. But to me, the most encouraging and uplifting factor of this historic occasion was the collective endeavor of so many countries working together to turn this tremendous source of energy away from a path of destruction into a field that will promote the mutual benefit of all.

• Technological developments of new sources of energy challenge our position as a "have" nation in terms of fossil fuels.

The major events influencing these realities have already occurred. For example, we don't have to estimate the number of people of marriageable age or how many people will join the work force by 1975, for they are already born. The greatest "chain reaction" occurred in 1954 and went almost unnoted by the press—the record birth of 4,060,000 babies.

We don't have to assume a rising curve of demand for electric energy during the next 20 years. We know it's going to rise. Only the rate of growth—the slope of the curve—can vary.

And we don't have to predict peacetime uses for atomic power. The plants are already being built in this country and in others. Within the next 25 years in many parts of the world, atomic fuels must supplement conventional fuel sources to meet the energy needs of expanding populations.

These realities must be faced. We must live with them—today and tomorrow. Ω

SCIENTISTS AND ENGINEERS FROM 72 COUNTRIES ATTENDED THE UN CONFERENCE AT THE PALACE OF NATIONS IN GENEVA, SWITZERLAND.

The Atomic Age Is Now

By BRUCE R. PRENTICE

This past summer, some 1260 delegates of 72 nations gathered at Geneva to exchange information and ideas on the peacetime uses of atomic energy (photo). It was a surprisingly earnest exchange, considering the ideologies and nationalistic outlooks of these countries. Barriers of language and political expediency melted and revealed to the world the great potential locked inside the atom.

There was a reason underlying this free exchange of nuclear know-how at Geneva. More than any other single factor, it was attributable to an awareness of a common need: namely, development of a source of energy that can supplement and eventually supplant the world's dwindling supplies of fossil fuels. Even those countries now fortunate enough to have supplies of coal, oil, and gas adequate to meet present demands are affected. They, too, must find, before the turn of the century, at least a supplementary source of energy.

Energy and Population

If in this country, for example, our population increases at its present rate, it will grow from the present 160-some million to 200-million people in 1975. Based on historical increases of electrical usage, America's electric generating capability will likewise increase from 102-million kilowatts at present to 375 million in 1975 and to 514 million in 1980. When you consider this combination—a mushrooming population and an increasing demand for power per person—it is reasonable to predict that our fossil-fuel reserves will be strained in 150 to 200 years.

There seems little choice between an outlook such as this and one that offers us a fuel supply that would probably last thousands of years under heavy demand as in fossil fuels. The answer then to the search for a new source of usable power lies in the atom—in nuclear power plants.

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Mr. Prentice—with GE 24 years—was formerly Manager of the Atomic Power Study that culminated in the establishment of the Commonwealth Edison Project. He is now Manager, Nuclear Systems Design Study, Atomic Power Equipment Department, Schenectady—responsible for design studies of new systems for nuclear power.

Pinning our hopes on the atom doesn't summarily exclude other means of producing power. Much has been said of directly harnessing the sun's energy. But most solutions suggested present problems of distribution and immediate availability of energy that do not face us in the atomic field.

Price Obstacle

The technology of atomic power is, to be sure, in its early stage. We are at the beginning of an era. But just as Henry Ford had a workable automobile, so we have a power-generating system that is entirely workable. Back in the days of Ford's first autos, it was probably cheaper to use a horse for transportation. Likewise, today it is still more economical to build and operate a conventional steam station. But this situation will change.

Pioneers in the atomic power field are pinning their hopes on several types of reactors, mainly the pressurized water, breeder, homogeneous, and boiling reactors. It is on the last one—a reactor that generates steam directly and bypasses intervening heat-exchange systems—that General Electric has based its dual-cycle boiling reactor.

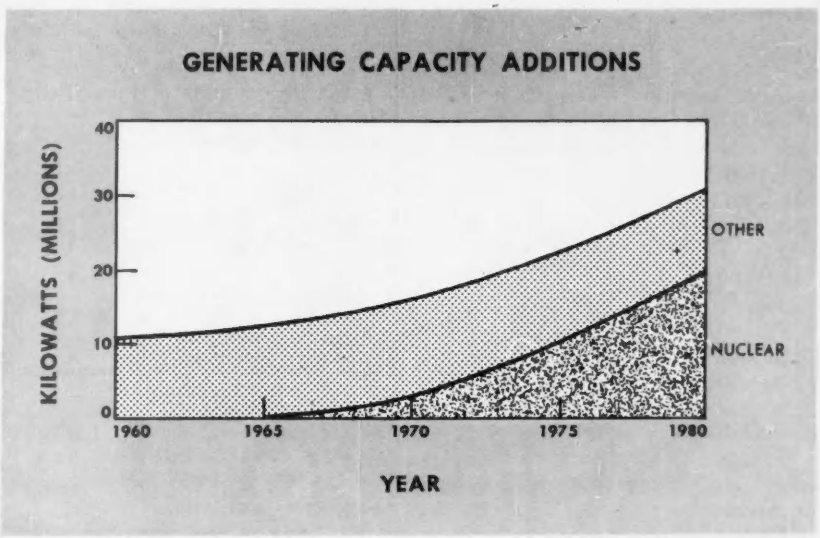
But power reactors, regardless of type, have the same basic end: to produce heat that can be harnessed in some way to drive electric generating equipment. All of them share the same basic problem. They are not now economical in operation. Considerable amounts of electric power can be produced but not yet at a competitive price. The only exception to this is where conventional power costs are abnormally high.

The problems are twofold: cost of fuel and cost of plant. Potentially, atomic fuels will cost substantially less than conventional fuels in most parts of the world. But the development needed and the time required are both significant. With lower fuel cost, an atomic plant can compete with a conventional plant even though it costs significantly more. But again, it will take a reasonable time to develop an atomic plant low enough in cost to produce competitive power from atomic fuels.

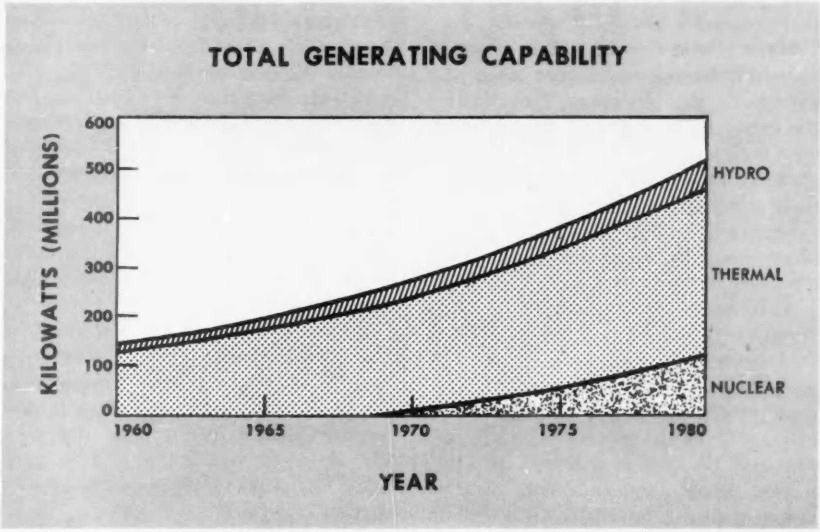
That this threat of high costs didn't cause business to wait until the AEC had carried atomic power still further toward the goal is a tribute to American free enterprise. The big steps in progress have invariably been initiated by courageous businessmen willing to venture beyond the current horizon—men prepared to take current losses and risk future losses, sometimes enormous risks. But then, this is what we've come to expect of foresighted members of American industry. If on such developments as electric refrigerators, automatic blankets, food-waste disposers, and even steam turbines industry had waited for encouragement through public demand and had withheld risk capital, we would never have known their benefits.

This time, industry has recognized the great potential locked inside a submicroscopic atom. And because this potential is undeniable, its leaders are investing and building for the future.

As an example, take the Commonwealth Edison Company of Chicago. It has contracted with General Electric for construction of the largest all-nuclear generating plant yet proposed, a 180,000-kw station (see article, page 19). And athough this plant will go on the line in 1960 as a reliable and integral part of Commonwealth's electric system, it will not produce truly economic or competitive electric power based on all the costs to General Electric, Commonwealth, or the other sponsoring companies. Each company involved is spending substantial amounts for the future, and the government has not been asked to spend one cent for this project.



BY 1980, NUCLEAR PLANT ADDITIONS ARE EXPECTED TO REACH 20-MILLION KILOWATTS A YEAR.



NUCLEAR POWER GENERATION WILL NOT MAKE CONVENTIONAL STEAM STATIONS OBSOLETE.

Conventional Competitor

Aside from their promise of alleviating our future shortages of fossil-fuel resources, nuclear power plants offer four major advantages . . .

- Versatility—an atomic power plant could be located virtually anywhere. Certain types, such as small packaged systems, could be moved even by air to a site with considerable ease.
- Small stockpile of fuel—a pound of uranium contains as much energy as do 1000 tons of coal.
- Cheaper electricity—eventually, atomic plants should be able to produce power considerably cheaper than conventional plants.
- Adaptability—nuclear power plants will be more adaptable to changing load demands.

While everyone recognizes the atom as the keystone to a great era ahead, another nagging question still remains: How long will it be before America has truly economic atomic power?

Many considerations and problems of a technical-economic nature affect the answer to this question. Forecasts of the expected decreases in nuclear plant cost and nuclear fuel cost have been made up to 1980. How nuclear plants—with different characteristic ratios of investment to fuel from conventional plants—will be integrated into a system has been studied.

This much would seem to be fairly certain. As nuclear power plant and fuel costs drop and as soon as it is possible to justify economically a nuclear power plant in a particular area, essentially all subsequent plants in that area will be nuclear powered. In other words, these nuclear plants will be operated throughout their life in the same manner as present steam-generating stations. Therefore, we have made economic comparisons based on a lifetime plant load factor of 50 percent.

Because of wide variations in fuel costs in different parts of the country, a nuclear power plant can become competitive sooner in some areas than in others. From a fossil-fuel cost-distribution analysis, it is possible to determine what percentage of the power generation in various parts of the country is from fuels at various cost levels.

The price of coal will probably remain steady over the next 20 years, mostly because any increase in labor costs will be matched by the savings possible through increased mechanization. Oil and natural gas, on the other hand, are expected to rise in price. We can anticipate, therefore, a gradual transition from oil and natural gas to coal, as well as some increase in the average fuel cost level.

NUCLEAR VS FOSSIL-FUEL PLANTS

Taking into account plant costs, fuel costs, and expected technological progress, the schedule of new plant construction should look something like this . . .

Year	Nuclear Plants (Percent of Total)	Conventional Plants (Percent of Plants)
1965	4	96
1970	14	86
1975	44	56
1980	65	35

We assumed that when the cost of generating power from a nuclear plant equalled the cost from a conventional steam plant we could expect 50 percent of all installations to be nuclear. When the cost of power from nuclear plants became 10 percent less than the cost from a steam station, it's safe to assume that all generating stations added would be nuclear. This simplest kind of economics permits us to go out on a prophetic limb (Box).

From this schedule, plus a consideration of the role of nuclear plants in large power systems, we can propose certain significant conclusions . . .

- By 1975, the annual additions of new nuclear-powered electric generating stations will be equal in kilowatts to the present total annual business in new generating plants (illustration, top, page 13). By 1980, new nuclear plant additions will reach 20-million kilowatts a year—twice the present figure.
- Nuclear power generation will not make conventional steam stations obsolete within a period longer than this estimate (illustration, lower, page 13), for several reasons. The required total generating capability is expected to increase to 375-million kilowatts in 1975 and 514-million kilowatts in 1980. Further, the long useful life of both conventional and nuclear plants is upwards of 30 years. As a result, even though our forecast shows the nuclear plant installation rate growing rapidly, the conventional thermal-plant installed capacity of some 90-million kilowatts in 1955 grows to 300-million kilowatts in 1975 and 350 million in 1980.
- Considerable time is required for a new energy source to pick up a substantial fraction of the nation's requirements. This underlines the great importance of vigorous development of nuclear power now so that a lack of fuel will not hamstring our expanding economy.

Paroxysm of Birth

The evolution of technology is slow. Even the industrial revolution, brought on by the invention of the steam engine, wasn't the cataclysmic event its name implies.

Similarly, when Edison achieved success with his incandescent lamp just before the turn of the century, it was hailed by millions yet bought by few. Almost no one knew of the private capital and exhausting hours that Edison and his associates put into the development of their dream.

Edison's lamp was useless by itself. To make it usable, entire new systems of electric generation, transmission, and distribution had to be developed.

Faltering at first, then gaining momentum, the Electric Age surged gradually onward throughout the world. And accompanying it came the wonders of electrical living that we now take so much for granted.

Based on this experience, it's apparent that we won't turn to atomic power overnight. As with the incandescent lamp, we have to begin at the beginning. That crude lamp was the keystone of an era. In the Atomic Age, our magic carpet is the nuclear reactor. It is the beginning. The way ahead is long, strewn with myriad problems of technology.

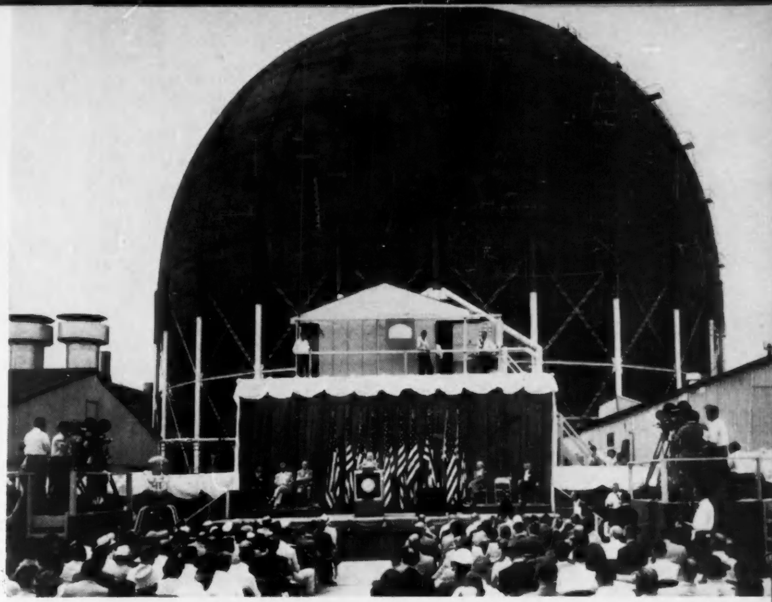
The birth of the atomic era is accompanied by controversies, as was the Electrical Age. What are the best reactors, the best fuels? How will the public benefit most by joint or independent activities of private industry and the government?

Opinions are often diverse and strongly held. The compelling forces of vigorous competition will settle some of the arguments through ventures risked to get at the facts. And, while the stimulus of aggressive competition is as strong today as in Edison's time, social standards of manners have progressed so that arguments are unlikely to be accompanied by hanging in effigy.

Just as the pioneers of the Electrical Age made a wild dream a practical reality, so too will today's scientists, engineers, and industrialists bring to fruition the age of atomic power. With it will come a degree of prosperity and progress that will make our present living standards pale by comparison.Ω

1939 G-E physicists K. H. Kingdon and H. C. Pollock prepare small samples of natural uranium for processing by electromagnetic separations method.

1955 First commercially distributed atomic-electric power is generated with heat energy from a submarine power plant inside a steel sphere at West Milton, NY.



Sixteen Years of Nuclear Technology

Review STAFF REPORT

Some of the diverse activities concerned with harnessing the atom are presented in this special issue. The articles represent a culmination of experience gained over 16 years of war and peace.

No one can foretell the future with certainty, but the past is history. For the record, we present a brief chronological report of General Electric's growth in what President Eisenhower has alluded to as the miraculous inventiveness of man—nuclear technology.

Genesis of Energy

In Washington, DC, on the afternoon of January 27, 1939, Denmark's Niels Bohr and Italy's Enrico Fermi made known to a conference of theoretical physicists an experiment carried out at Columbia University a few days earlier. It confirmed that bombarding natural uranium with neutrons produced a lighter element, barium; but contrary to expectations, no great amount of energy was liberated.

Shortly afterward, Bohr and Princeton's J. A. Wheeler theorized that U-235, present in natural uranium in a ratio of 1 to 140, was the fissioning element. They further theorized that excess fission neutrons capable of sustaining a chain reaction—and producing enormous amounts of energy—were absorbed by nonfissionable U-238.

To substantiate the theory, two groups immediately set out to isolate some U-235: the University of Minnesota and GE's Research Laboratory.

Both groups succeeded. A small sample of U-235 obtained by A. O. Nier of the University of Minnesota was quickly followed by the separation of a slightly larger amount at GE's Research Laboratory in March, 1940. By firing electrons into a gaseous compound of uranium tetrachloride, G-E physicists Kenneth H. Kingdon and Herbert C. Pollock obtained positive ions of uranium. These were then accelerated in an electric field and U-235 atoms magnetically deflected onto a target.

Both samples were rushed to Columbia University where theoretical predictions were confirmed.

The Bomb

Early in 1941, Dr. W. D. Coolidge, director of research at GE was appointed to a scientific reviewing committee of the National Academy of Sciences. Instructed to evaluate the military importance of uranium, this committee was also to recommend our country's expenditure for investigating the problem. And in November, 1941, they reported that an atomic bomb was probably feasible and would likely be of decisive military significance.

As a direct result, the huge Manhattan District of the Army Corps of Engineers was established.

Logically enough, the contributions of GE that followed concerned the separation of U-235—the bomb's explosive ingredient. For of the two main processes subsequently employed at Oak Ridge, one was the electromagnetic method.

To the University of California at Berkeley fell the job of scaling up, by a factor of 10 million, the yield of U-235. Numerous G-E scientists and engineers worked with the University's staff for almost three years. They supplied material for the first experiments, and cooperated closely in designing and supplying various equipment.

Another larger group of G-E scientists and engineers was based at Oak Ridge. They engineered certain electric equipment and systems needed for the process there.

Ultimately, the main method used at Oak Ridge for isolating U-235 was gaseous diffusion. Primarily a physical-chemical process, it is based on the principle that two gases of different atomic weight can be separated by allowing some of the mixture to diffuse through porous barriers.

For this process, GE carried on a vast program of development and manufacturing. Much of the equipment needed, particularly the complex instrumentation devices, had to be built from the ground up. Nothing like the instrumentation existed before. In addition, GE

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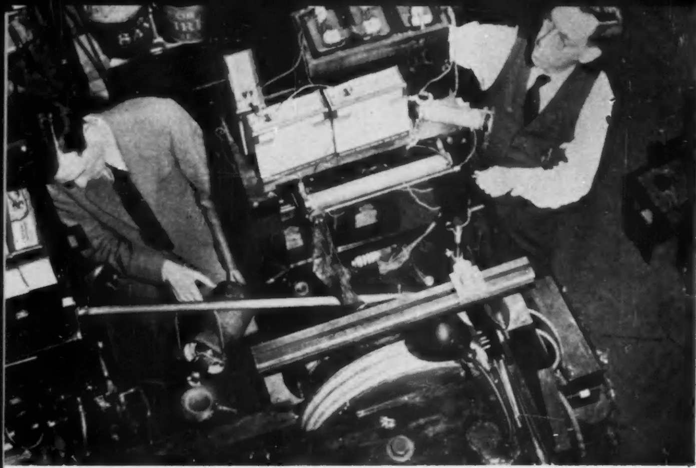
OVERLEAF: PICTORIAL HISTORY OF NUCLEAR DEVELOPMENTS



1940: URANIUM

Dr. Pollock and Dr. Kingdon isolate a fraction of a microgram of uranium-235 with this electromagnetic apparatus. Tests later made on the sample at Columbia University proved beyond a doubt that U-235 is the fissioning element in natural uranium.

1946: PLUTONIUM

GE takes over operation of the government-owned Hanford Operation near Richland, Wash. This is but one of the several large production facilities for producing plutonium that are scattered over 600 square miles of land bordering on the Columbia River.

1947: RESEARCH

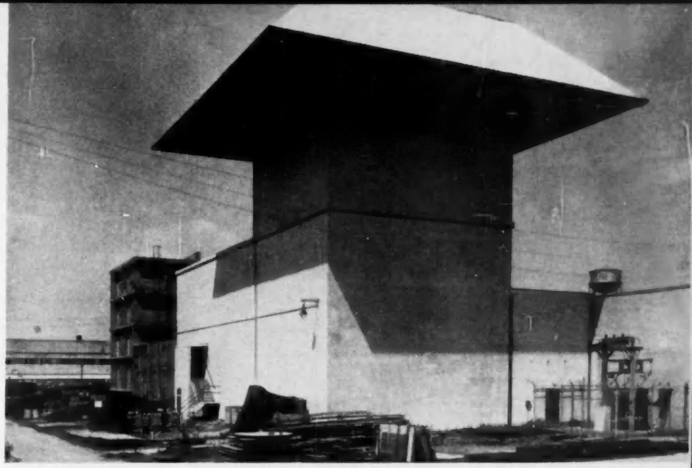
Research and development in reactor technology for power applications are initiated at the government-owned Knolls Atomic Power Laboratory near Schenectady. This group also gives technical assistance to the Hanford Atomic Products Operation.

1950: SUBMARINE

The Knolls Atomic Power Laboratory defers work on peacetime breeder reactor to develop a submarine intermediate reactor. Less than two years later, the foundation is laid for a steel sphere to house the land-based prototype of the submarine nuclear power plant.

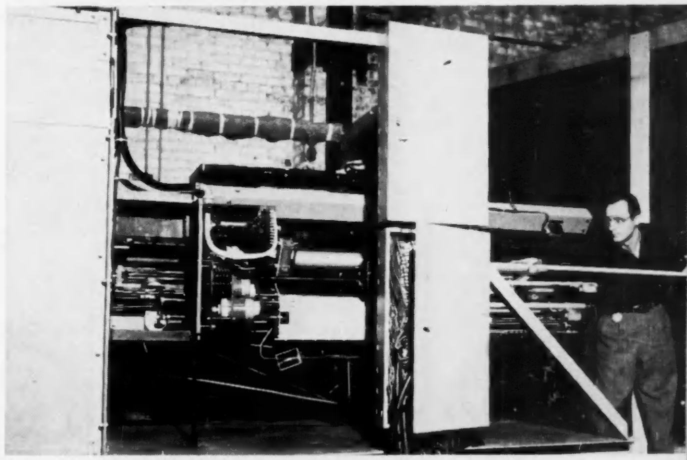
1951: AIRCRAFT

Development of a nuclear power plant for aircraft is initiated upon request of the AEC and the Air Force. This pagoda-like building is an engine test cell located at the Aircraft Nuclear Propulsion Department's plant in Evendale, Ohio.



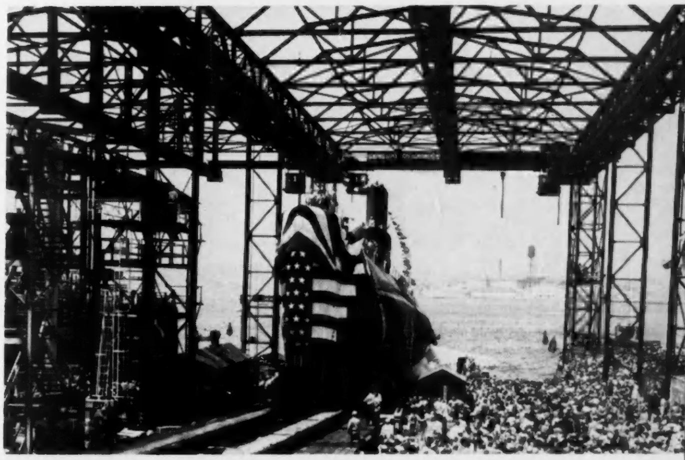
1955: REACTORS

Nuclear research reactors for industrial, educational, and research organizations are offered on the commercial market for the first time. This packaged 30-kw nuclear test reactor is one of four types with ratings up to 5000 kw now available to the public.



1955: *SEAWOLF*

Atomic submarine SSN575 *Seawolf* is launched at Groton, Conn. The land-based prototype of her nuclear power plant at West Milton, NY, had already been operated long enough to have propelled the ship 2250 miles, nonstop and fully submerged.



1955: GENEVA

United Nations International Conference on Peaceful Uses of Atomic Energy is held at Geneva. UN Secretary General Dag Hammarskjold (left) converses with F. K. McCune (light suit), Vice President and General Manager of GE's Atomic Products Division.

had to engineer a complete electric power system for the process and negotiate with scores of subcontractors.

In another part of the country, far removed from Oak Ridge, another material with the same fissionable characteristics of U-235 was being produced—plutonium, subsequently used in the Hiroshima atomic bomb. In 1943, under contract with the Manhattan District, the E. I. du Pont de Nemours Company had constructed a $350-million plant for producing plutonium at Hanford, near Richland, Wash.

At the end of the war, when du Pont asked to be relieved of their responsibility at Hanford, the government requested that GE take over. Although GE declined at first, they accepted when the contract request was repeated in September, 1946.

Almost immediately, GE began expanding and renovating the Hanford operation, adding a fourth huge nuclear reactor. Moreover, methods of production were improved, new tools and equipment developed, and a fund of nuclear knowledge accumulated in reactor engineering, metallurgy, chemistry, biology, and related sciences.

The Hanford Atomic Products Operation, as it is known today, is a big undertaking. But the results speak for themselves: plutonium production has increased many times over and its unit cost reduced considerably.

Manhattan District, with whom GE contracted to operate Hanford, was discontinued in 1946. Congress then created the AEC as the contracting agency.

Atoms for Defense . . .

The contract called for a nuclear laboratory in Schenectady in addition to the Hanford operation. Basically, the aim of the new laboratory would be development of nuclear reactors and the collateral activities that arise in the production of power from nuclear sources. And in addition, technical assistance to Hanford would have the highest priority.

Construction of the laboratory's permanent buildings began in the summer of 1947 near The Knolls, a private estate on the outskirts of Schenectady. At first, it was administered as a division of GE's Research Laboratory. Then in mid-1950 the technical staff moved into their new home, and the Knolls Atomic Power Laboratory became a self-contained but integral component of GE, operated for the AEC.

One of KAPL's many projects had been an experimental power-breeder reactor that would produce power and at the same time convert natural uranium into a nuclear fuel. In April, 1950, however—two months before the outbreak of the Korean War—its development was deferred in favor of the submarine intermediate reactor (SIR) project. Much of the work done previously on the experimental breeder was applicable to SIR.

The following year, AEC and the Air Force approached General Electric with still another challenging problem: the development of a nuclear propulsion system for aircraft. Primarily, this selection was based on two factors: GE's experience in developing jet engines and in atomic energy. Before long, the new operation was established as the Aircraft Nuclear Propulsion (ANP) Department, with headquarters in Evendale, Ohio, and an equipment-testing site at Idaho Falls, Idaho.

As February of 1952 approached, the SIR project had advanced to the point where AEC could authorize construction of a land-based prototype of the submarine nuclear power plant. For this purpose, erection of a huge steel sphere began on AEC-owned land at West Milton, NY, about 20 miles north of Schenectady. The prototype power plant would be tested inside the 225-foot sphere, its steel walls containing any radioactivity that might be released in the remote event that all power-plant control failed simultaneously.

Typifying the rapid progress at that time, KAPL started development of still another atomic power plant—the submarine advanced reactor (SAR).

By September of 1953, GE's atomic power activities had become so diversified that some new organizational step was necessary to co-ordinate the work. Thus was created the Atomic Products Division, comprised at that time of the Hanford Atomic Products Operation at Richland, Wash., the Knolls Atomic Power Laboratory at Schenectady, and the Aircraft Nuclear Propulsion Department at Evendale, Ohio.

. . . and Peace

Some 18 months later, in March of 1955, a new department was added to the Atomic Products Division to centralize all activities related strictly to peacetime applications of atomic energy. The new group, called the Atomic Power Equipment Department, would be responsible for developing and selling a complete line of atomic power equipment.

In a sense, 1955 was a banner year for nuclear technology, much of the labor and planning of previous years coming to fruition.

During April, GE announced that it would design and build the world's largest all-nuclear power plant for Commonwealth Edison of Chicago. A 180,000-kw dual-cycle boiling-water reactor, this unit is a major advance in the economic generation of atomic power.

Scarcely two months later, in June, GE's newly formed Atomic Power Equipment Department initiated another milestone in peacetime applications of the atom. It began America's first co-ordinated sales program for nuclear research reactors. Four types were offered to the public: a 30-kw nuclear test reactor, a 50-kw water-boiler reactor, a 1000-kw swimming-pool reactor, and a 5000-kw heavy-water reactor (see article, page 27).

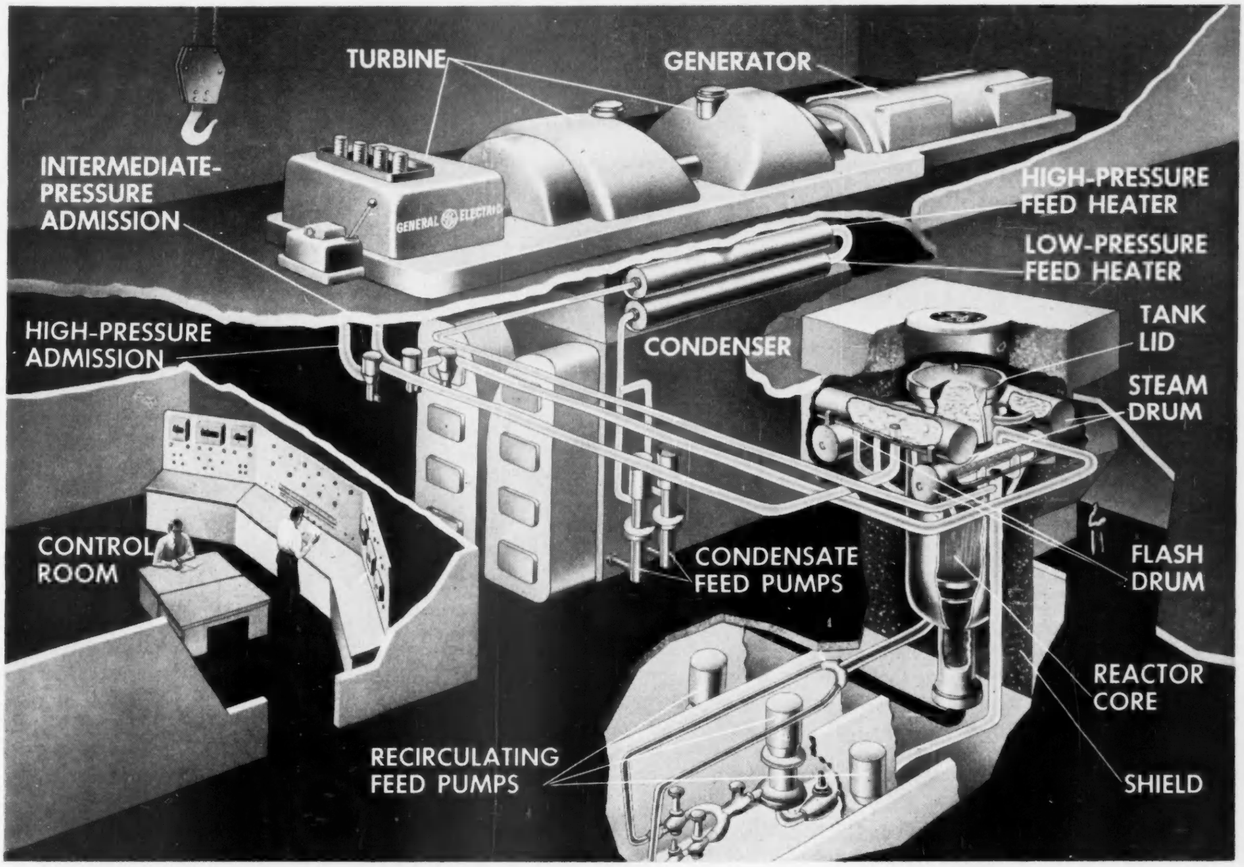
Two events of equally great significance marked the month of July.

The first occurred at West Milton, site of the steel sphere housing the prototype submarine nuclear power plant. By-product energy from the experimental reactor, powering a steam turbine-generator, sent electricity to homes, farms, and industries in the surrounding area. It marked the first commercial distribution of atomic power anywhere in the free world. Chairman Lewis L. Strauss of the AEC, throwing the switch, said, "What we are about to do may well stand as a symbol of our hopes and aspirations for the day when the atom will serve only as the servant of man. . . . "

Three days later, 20,000 spectators watched the atomic submarine *Seawolf* slide down the ways at Groton, Conn. Significantly enough, its prototype reactor at West Milton had already operated under full power sufficiently long to have propelled the ship 2250 miles, nonstop and fully submerged.

Finally, in August, came the beginning of the free world's dream—the United Nations International Conference on Peaceful Uses of Atomic Energy at Geneva, Switzerland. Attending were 19 G-E scientists, engineers, and officials, plus an exhibit of GE's dual-cycle boiling-water nuclear reactor and other atomic equipment. They presented 14 technical papers to the historic conference and freely exchanged information with scientists of other lands.

After 16 years, nuclear technology is showing signs of universal service.—JJR



COMMONWEALTH EDISON'S 180,000-KW NUCLEAR POWER PLANT, TO BE LOCATED 47 MILES FROM CHICAGO, WILL BE COMPLETED BY 1960.

Commonwealth Edison's Nuclear Power Plant

By TITUS G. LeCLAIR and SAMUEL UNTERMYER

Two years ago, under an agreement with AEC, a group of electric utilities and an engineering and construction firm undertook a study of nuclear power reactors. The objective: selection of one or more types of power reactors that could be developed for use in a generating plant in the near future. Further, late models of this design should be able to produce power at commercially competitive rates.

Members of this study team, known as the Nuclear Power Group, were American Gas & Electric Service Corp., Bechtel Corp., Commonwealth Edison Company, Pacific Gas & Electric Company, and Union Electric Company of Missouri.

After a period of study, they concluded that the boiling-water reactor would best fulfill the objective. AEC's Argonne National Laboratory had conducted many experiments to test the features of the boiling-water principle and currently is building a pilot plant to further develop the techniques. Extending the work, General Electric studied the reactor to determine how its performance could be improved to make it even more suitable for a large central-station generating plant. One modification—the dual-cycle boiling reactor—showed much promise and warranted commercial development.

With the choice of reactor established, the Nuclear Power Group and GE joined hands in a design study and cost estimate for a full-scale plant that would utilize a dual-cycle reactor. The study showed that future plants would be competitive (Box, page 22), although the first 180,000-kw plant of this type would produce electric power at a cost higher than a comparable steam plant.

The joint studies indicated that the Nuclear Power Group, other utilities in America, and the nation as a whole would benefit from the design and construction of such a power plant.

This year, on March 31, Willis Gale, Chairman, Commonwealth Edison Company, said: "A proposal for the construction of a full-scale nuclear power plant has been submitted to the AEC by Commonwealth Edison on behalf of the Nuclear Power Group.

"General Electric will be the prime contractor and Bechtel Corp. will act as engineer-constructor for GE."

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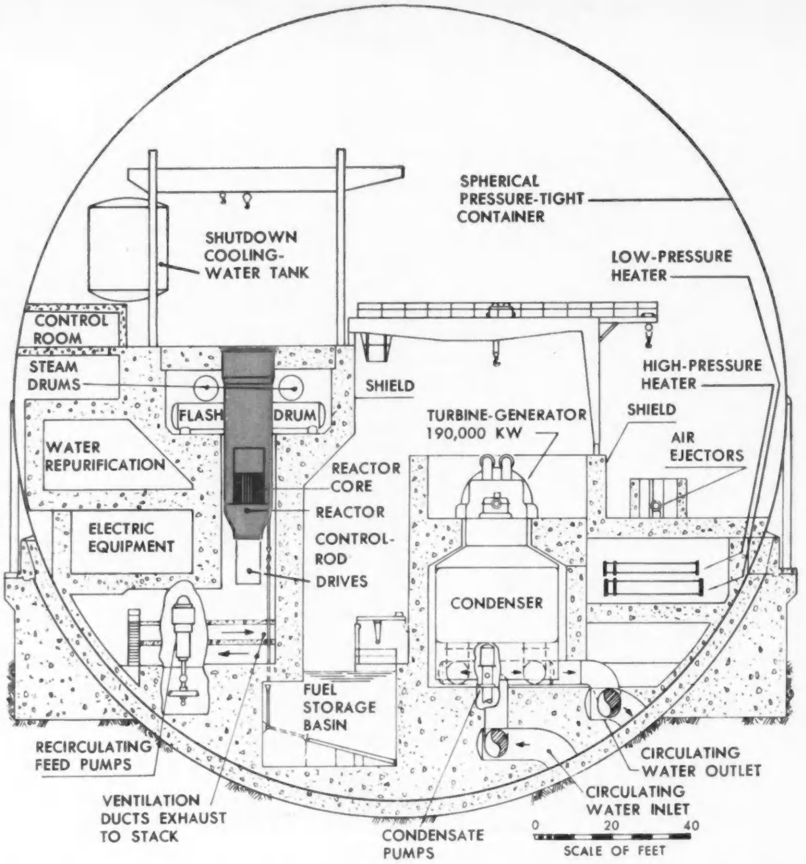
OVERLEAF: DETAILS OF NEW PLANT AND DUAL-CYCLE REACTOR

Details of Commonwealth Edison's New Atomic Plant



CROSS SECTION OF NEW PLANT'S SPHERE SHOWS PRELIMINARY ARRANGEMENT OF EQUIPMENT.

The principal station components of Commonwealth Edison's nuclear power plant are housed in an airtight sphere 200 feet in diameter (illustration). This assures safety to the surrounding area in case of an incident because the sphere is designed to contain the internal pressure that would result if all the water in the reactor were to escape in the form of steam. The sphere is ventilated via a stack that can be blocked off during an emergency.

The reactor and associated equipment are surrounded by a thick concrete shield (illustration, page 19). The control room—the plant's nerve center—is located on the upper level to give a good top view of the reactor during maintenance and reloading. (Throughout reloading, enough water is maintained above the reactor core to provide biological shielding.)

During a power failure, heat from the reactor is removed by condensing steam and returning the condensate by gravity to the reactor vessel. Evaporating the water at atmospheric pressure cools the condenser. An overhead tank stores water for cooling the shutdown condenser.

During operation, isotopes of oxygen that are formed when neutrons strike oxygen atoms are the major source of radioactivity in the steam-and-water system. When the plant is shut down, the value of these isotopes in the water becomes insignificant in about five minutes.

Corrosion products and other impurities in the water that have become radioactive in passing through the reactor core are an annoying source of radioactivity. Tests have shown that the only solid impurities transported with the steam are those that are entrained by minute droplets of water. But with efficient moisture separators, the steam will contain only about one ten-thousandth of the concentration of radioactive solids present in the water.

To reduce this residual radioactivity, the concentration of impurities in the reactor water is maintained at a low level by continuously bypassing a portion of the water through a cleanup filter and demineralizer.

Only a small fraction of the impurities in the steam will adhere to the turbine. Thus any difficulty appears unlikely in maintaining the turbine and associated equipment under normal conditions.

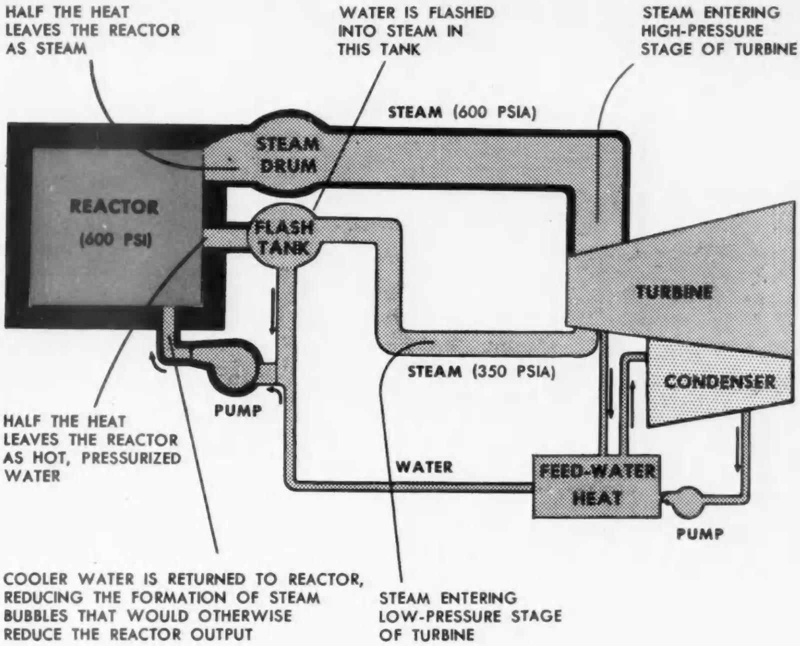
A net plant thermal efficiency of 26 percent, or 13,000 Btu per kilowatt-hour, is expected. (A net thermal efficiency of a good conventionally fired steam plant is from 33 to 38 percent.) This reactor will achieve a thermal efficiency and performance that would be characteristic of a pressurized water reactor operating at three to four times the pressure.

Service facilities for the new power plant are grouped around the sphere (front cover). The administrative offices and plant laboratory are located in front of the sphere. To the right are the maintenance shops, equipment stores, personnel locker facilities, and associated offices. To the left, the service area includes water-treating facilities; ventilation, heating, and cooling equipment; and emergency stand-by power equipment.

A separate building stores both new and spent fuel elements, as well as cleanup facilities for personnel, clothing, and contaminated equipment.

By 1960, when this new plant will start operating, Commonwealth Edison's entire system will have a capability of 4½-million kilowatts, as compared with its present total of 3,600,000 kw. Of the expected total, the nuclear plant will contribute approximately 4 percent.

Dual-Cycle Reactor Offers Good Efficiency, Inherent Safety



DUAL-CYCLE REACTOR ADDS TO THE BEST FEATURES OF THE BOILING-WATER REACTOR.

Pressurized-water reactors pack a lot of power in a small package, but they're handicapped by a heat exchanger and by the armor-like construction necessary to handle the high pressures.

The boiling-water reactor simplifies matters by generating steam within the reactor itself; the steam is then used directly in the turbine. And the system is inherently safe. At the Argonne Laboratory, control rods were suddenly jerked out of a boiling-water reactor. Instead of running away, the reactor shut down. Steam formed by the power surge effectively choked the chain reaction.

Along with the advantages of high safety, no heat exchanger, and relatively low pressures and temperatures, the boiling-water system has some fundamental weaknesses. As the water boils, its density fluctuates, causing an uneasiness in the chain reaction and, therefore, a variation in the power level. Control rods aren't of much value in smoothing out these humps. To get satisfactory control and reasonable steam output, an abnormally large reactor would be necessary.

Another difficulty is the behavior of a boiling reactor during a change in load. A demand for more power boosts the steam flow from the reactor, causing a reduction in reactor pressure. As a result, water flashes into steam within the reactor. This sudden formation of steam actually strangles the chain reaction, reducing reactor output just when more power is needed.

General Electric's dual-cycle reactor not only retains the advantages of the boiling reactor—simplicity, low pressure and temperature, and safety—but also is a self-regulating device.

In the dual-cycle boiling reactor (illustration), the flash-tank system, operating in conjunction with the boiling cycle, furnishes the subcooled water. Operating pressure within the reactor is 600 psia. The flash system produces 350-psia steam that is admitted to an intermediate turbine stage. Water from the reactor passes through the flash vessels where pressure is reduced, causing a fraction of the water to be converted into steam, while the remainder is cooled. This water is then pumped back into the reactor to provide the subcooling required.

How does the reactor stabilize itself under varying load demands? Most of the turbine-governor adjustment for load variations takes place in the 350-psia admission. Consequently, the subcooling in the reactor increases with load. When there is a demand for more power, the turbine governor acts to admit more steam from the flash tank, while the flow of steam into the 600-psia, or high-pressure, stage is not immediately affected. As the steam demand from the flash tank increases, the pressure drops so that more water flows into the tank. The flash pump draws off more water from this tank to hold a constant level, and the amount of subcooled water entering the reactor increases. The amount of steam within the core consequently is reduced, and the reactor output rises to meet the load demand. Safety is not sacrificed during load changes; if the power of the reactor should increase suddenly, the reactor would fill with steam. This would drive out the water and, as a consequence, shut down the reactor.

The dual-cycle reactor in Commonwealth Edison's new plant (illustration, page 19) consists of a vertical array of slightly enriched uranium-dioxide rods. They are supported in hexagonal zirconium coolant channels arranged in a regular pattern. These coolant channels extend above the reactor core to form chimneys that are used to promote natural circulation of the steam-water mixture.

Control of the dual-cycle reactor is by vertical control rods, actuated by hydraulic pistons. There are enough rods so that it is possible to move an individual rod quite freely without materially affecting the chain reaction.

The simplicity and small size of this dual-cycle boiling reactor, compared with a conventional boiler, gives a visual indication of the future potential not only for cost reduction but also for vigorous competition with conventional steam plants.

All Boards of Directors of the five companies participating in the Nuclear Power Group approved the proposal on April 10. In the meantime, the Central Illinois Light Company, Illinois Power Company, and the Kansas City Power & Light Company joined the original group. At the end of 1954, the seven utility companies in the Nuclear Power Group had a total generating capacity of 14½-million kilowatts in 12 of the 48 states, accounting for approximately one seventh of the total generating capacity of the public and privately owned utilities in the United States.

It was also announced on April 10 that the plant would be located on a 750-acre site of farmland near the confluence of the Kankakee and Des Plaines Rivers in Grundy County, Ill., 47 miles southwest of Chicago.

On July 22, General Electric and the Commonwealth Edison Company signed the official contract that calls for GE to build the 180,000-kw dual-cycle-reactor generating plant at a cost of $45 million —probably the largest single-unit sale in GE's history. The project, financed entirely with private funds, is the largest plant yet announced to produce electric power exclusively from nuclear fuel. The completion date is scheduled for 1960.

With the signing of the contract, the eight sponsoring companies formally incorporated to carry out the research and development part of the construction.

Simultaneous with the opening of the United Nations International Conference on the Peaceful Uses of Atomic Energy in Geneva, Switzerland, the AEC formally approved the plans on August 8.

Site Selection

Factors that influenced the selection of the site for this nuclear-fueled power plant were similar to those for a conventional plant except that easy access to an economic fuel supply is not necessary.

But other considerations remained. An adequate supply of cooling water takes on added importance because of a nuclear plant's lower thermal efficiency and greater cooling requirements. Location of the plant with respect to existing transmission lines and load centers was another factor.

The location of the Dresden Generating Station, as the new plant will be called, fulfilled these requirements. The available cooling water would be enough for a plant of one-million kilowatts, and an existing 138-kv transmission line is only two miles away.

(You'll find details of the new plant and the dual-cycle reactor on pages 20 and 21.)

POSSIBILITIES FOR FUTURE PROGRESS

The performance of the dual-cycle boiling-water reactor depends, of course, on operating temperatures and pressures. And for a pioneer installation such as Commonwealth Edison, the chosen conditions insure successful operation. The experience from research progress and plant operation will undoubtedly permit the use of higher temperatures and pressures in later models of the reactor. For instance, tripling the pressure from 600 to 1800 psia would boost the thermal efficiency from 26 to 32 percent. And it will become possible to generate a larger portion of the steam within the reactor vessel—reducing the size and the cost of the external equipment.

At the same time, manufacturing progress will probably reduce the first cost of dual-cycle reactors. Finally, the fuel cost may also decrease.

About the Financing

Admittedly, this new atomic power plant will be unable to compete economically with present-day conventional power plants. Today's modern fossil-fuel plant can generate power for about three fourths of a cent per kilowatt-hour; the cost for power from the Dresden Station will be about one cent per kilowatt-hour. Looking at it another way, the proposed plant will cost $250 per kilowatt compared with the $167 that a conventional installation of the same capacity would cost.

Financing the plant was based on the premise that no one company could justify a greater capital investment in a nuclear plant than in a conventional plant. With about $30 million involved in a conventional 180,000-kw plant, someone would obviously have to pick up a tab of $15 million.

The problem was resolved in this way: Commonwealth Edison will capitalize the $30 million and utlimately own and operate the plant. Over a period of five years, the members of the Nuclear Power Group, Inc., will put $15 million into the new research corporation that in turn will supply the $15-million balance of the contract price. In return for their money, the companies will gain technical information, experience, and training that can be obtained only from day-to-day participation in designing, building, and operating a full-scale nuclear plant.

Under the proposed plan of financing, no request will be made for government funds or for accelerated amortization of the capital cost.

Because the plant is expected to cost more than the contract price of $45 million, General Electric will be making substantial research and development expenditures.

Teamwork for Progress

Commonwealth Edison and General Electric look upon this development as another milestone in electric power generation.

In the spring of 1903, the principal officers of these two companies met at the Fisk Generating Station in Chicago to witness the starting of the first all-steam-turbine generating plant to be constructed. Although this steam turbine was slightly less efficient than the reciprocating engine it supplanted, the management of the two companies recognized its potentialities and had the courage to construct a 5000-kw unit—a large generator for those days.

More than 50 years later, with the support of seven associates, the two companies are again undertaking a major project involving financial and technical uncertainties. All are confident that this project will demonstrate the efficient utilization of a new source of energy for the world's increasing needs. Ω

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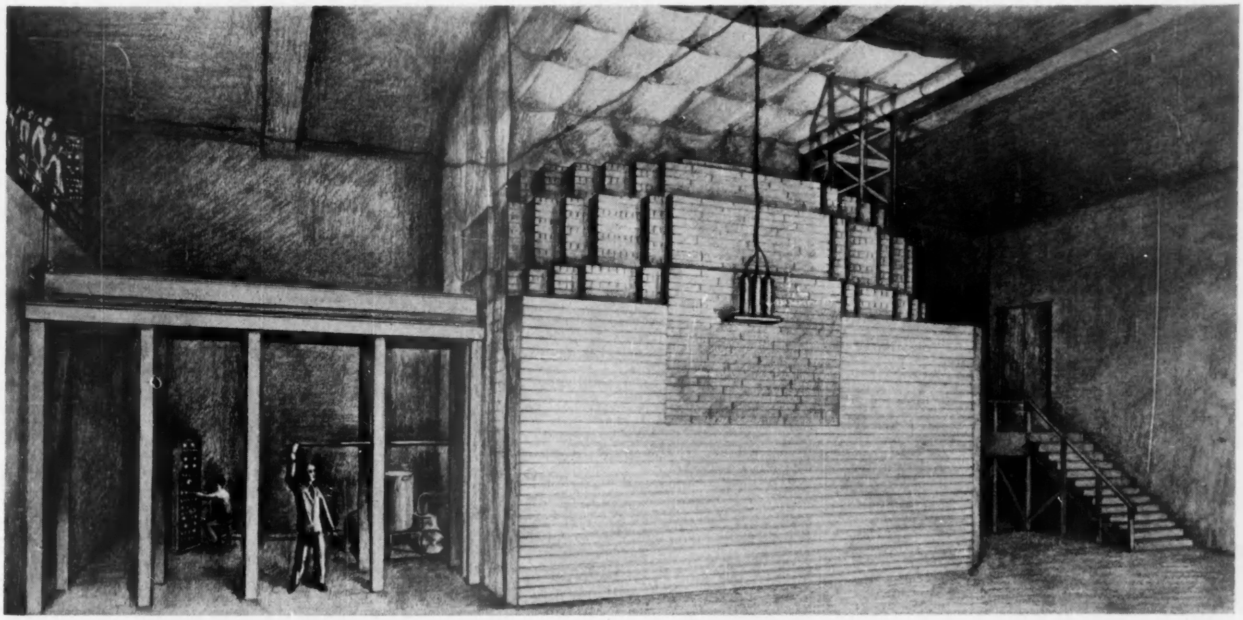
Beginning his career with GE in 1921, Mr. LeClair joined the Commonwealth Edison Company in Chicago two years later. He is presently Engineering Assistant to the Vice President, with responsibilities in technical and engineering matters. Author of many engineering papers and Past President of the AIEE, he served as Chairman of the Operating Committee of the Nuclear Power Group. Mr. Untermyer, formerly with AEC's Argonne and Oak Ridge Laboratories, has done extensive design and development work on nuclear reactors. An engineer in GE's Atomic Power Study, Atomic Products Division, Schenectady, since 1954, he was responsible for the initial design of the dual-cycle reactor.



FIRST NUCLEAR REACTOR, ERECTED IN 1942 AT THE UNIVERSITY OF CHICAGO, NOW FUNCTIONS AT THE ARGONNE NATIONAL LABORATORY.

Highlights of Reactor Technology 1942–1955

BY DR. M. C. LEVERETT

At the University of Chicago's Argonne Laboratory, when in 1942 for the first time man initiated a nuclear chain reaction, those present sensed the importance of the occasion. For a few moments on that historic December afternoon, thoughtful speculation and discussion centered on the uses of atomic energy other than in the destructive bomb. A glance at the 13 intervening years will show what has happened in the exciting, demanding, and complicated field of reactor technology.

Growth in this field can possibly be measured by the different types of reactors built and the number of new groups who have built them since 1942.

The first reactor (photo) of the chronology is, of course, the graphite-moderated reactor called CP-1—the key actor in the drama just described. During the following year, the CP-2 quickly succeeded the original reactor. It had no cooling system and never ran at more than a few kilowatts for any sustained period, although occasionally it operated at higher power for short periods. The reactor's fuel was uranium and its oxides; its moderator, graphite; and its shield, concrete. Although little more than a large critical experiment, the usefulness of this reactor lasted for a long time.

The graphite reactor at the Oak Ridge National Laboratory went into operation that same year. This reactor was a large cube of graphite pierced with many holes in which aluminum cans containing uranium cylinders, or slugs, were placed. Fans pumped air through the space surrounding the cylinders. A series of minor changes in design and auxiliary equipment gradually increased the initial power of approximately 800 kw to several times this figure.

Really the first power reactor, it produced energy at so low a temperature as to be almost useless. However, in postwar years a miniature steam boiler was constructed and put into the reactor, which heated it by nuclear processes.

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Dr. Leverett—Engineering Manager, Aircraft Nuclear Propulsion Dept., Evendale, Ohio—has been with General Electric since 1951. He entered the atomic field in 1942 on the atomic bomb project. Working largely with reactors, he was a member of the group that conceived and did the initial designing of the Hanford reactors and was in charge of engineering on the Materials Testing Reactor.

The steam produced drove a tiny generator, and the resultant power lit an electric lamp—quite possibly the first example of useful electricity from a nuclear chain reaction.

In 1944 the first reactors of really high power—the graphite-moderated water-cooled reactors—were put into action at Hanford. For fuel elements they also used uranium cylinders canned in aluminum to protect them against the action of the cooling water.

During the same year the first heavy-water-moderated reactor was put into operation, also using aluminum-clad uranium slugs as the fuel elements. These were bathed in heavy water that served both as coolant and moderator.

Also in 1944, Los Alamos introduced the first homogeneous reactor—the type known as the water boiler (photo, page 26)—that used a solution of enriched uranyl nitrate in water.

No new reactor types were placed in operation during the next two years. But in 1947 the Canadians began to operate the so-called NRX reactor. Although moderated with heavy water, it was cooled with light water. And uranium slugs again clad with aluminum served as the fuel elements.

Another year passed before the first fast neutron reactor came to life at Los Alamos. Its fuel was plutonium, its coolant mercury.

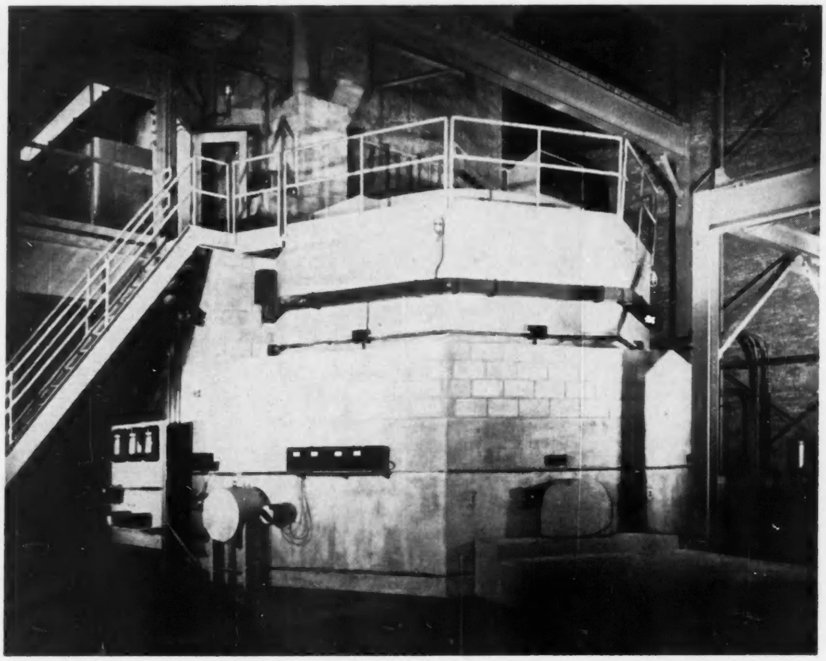
In 1950 a lineal descendant of the Oak Ridge graphite reactor was put into operation at the Brookhaven National Laboratory, Long Island. This air-cooled reactor used uranium slugs canned in aluminum. Certain engineering techniques greatly increased its power over that of the Oak Ridge reactor.

Placed into operation in 1951 was the first of the alkali-metal-cooled reactors: the sodium-potassium-cooled U-235 fueled fast-neutron Experimental Breeder Reactor (EBR), built at the National Reactor Testing Station by Argonne National Laboratory (photo). The first to explore fissionable fuel breeding and prove it to be technically feasible, the EBR generated about 250 kw of electric power.

Since 1951, other reactors have become operational: the Materials Testing Reactor (photo, next page), the Homogeneous Reactor Experiment, the Submarine Thermal Reactor (STR), the Submarine Intermediate Reactor (SIR), the North Carolina State Reactor (homogeneous water boiler), the Savannah River Reactors, and the first of the North American Aviation Reactors.

Two recent types of reactors are the boiling-water reactor being developed at the Argonne National Laboratory, and its direct descendant, the 180,000-kw G-E dual-cycle reactor being developed for the Commonwealth Edison Company and a group of associates. Financed entirely by private industry, the dual-cycle reactor is noteworthy for its advanced technical conception (see article, page 19).

The conclusion of this chronology leads to an apparent question: During the 12 years of building more than 30 different types of reactors, how much new technology was developed and what new scientific discoveries were made? Nuclear physics stands out as one important area benefiting from the reactor business.



EBR Generating about 250 kw of electric power, the Experimental Breeder Reactor was the first to explore fissionable fuel breeding and prove it technically feasible.

Nuclear Physics

The fundamental physics of the nuclear chain reaction worked out in 1941 and 1942 remains almost unchanged. The many advances and new discoveries that have arisen in the broad field of nuclear physics resulted more from continued research into the basic nature of the nucleus than from reactor development and technology.

Reactor technology and science have led to much measurement of cross sections, many elaborate mathematical treatments of the reactor equations, and discovery of new and extremely interesting nuclei—such as xenon 135 with its colossal absorption cross section that almost blocked the first Hanford reactors. Knowledge of the numbers and origins of delayed neutrons that follow fission has been increased. And some new elements, through No. 100, have been created, particularly by Seaborg and his co-workers. Even with these developments, reactor physics today would be much the same to the physicist of 10 or 11 years ago.

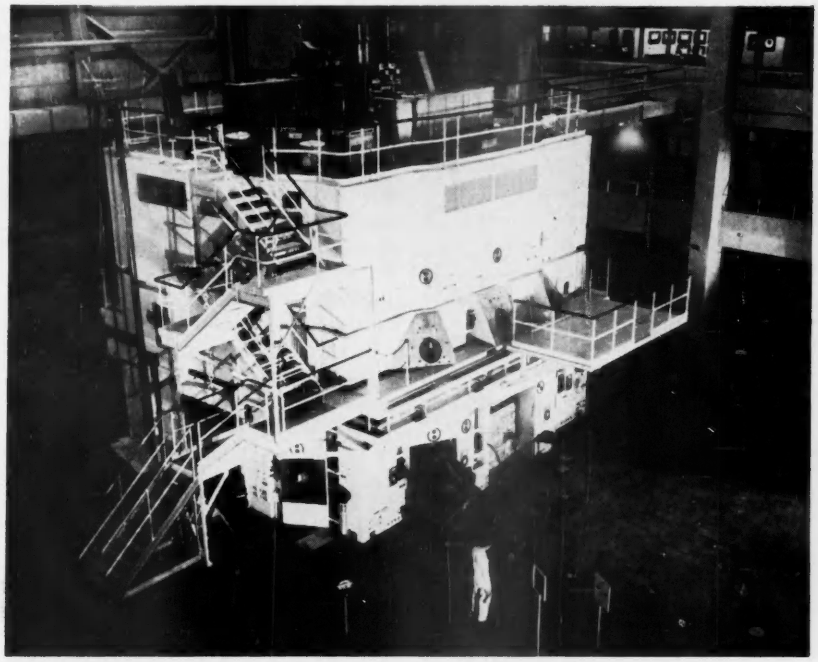
Throughout reactor history, one particular characteristic of reactor physics has remained constant: Essentially, it's impossible to calculate with sufficient accuracy all the desired characteristics of a new type of nuclear reactor, making experimentation unavoidable. Thus critical experiments—one type of nuclear reactor experiments—are an integral part of any serious reactor design and development installation.

In the art of shielding, notable advances permit shields of much lighter weight than would have been necessary for the same reactor in 1943 or 1944. These advances, however, have come not as a result of ever more refined and abstruse theoretical work but from direct, practical, experimental measurements of the shielding effectiveness of various materials and combinations.

One interesting concept, the divided shield, resulted from attempts to find lightweight shielding systems, particularly for mobile power plants such as those used in aircraft. First recorded in an official report by the North American Aviation Company in 1948, and independently rediscovered shortly thereafter by the Nuclear Energy for Propulsion of Aircraft (NEPA) project at Oak Ridge, this conception has been extensively developed by the various groups working on aircraft nuclear propulsion. The divided shield is so named because a portion of the shielding is placed around the reactor proper, the remainder around personnel. The combined weight of the two shields is generally less than the weight of a single shield thick enough to safely reduce the reactor radiation.

Engineering Technology

Although you hear much about the new engineering techniques that either have been or must be developed in nuclear-energy exploitation, a critical look would indicate otherwise. For the only new basic engineering technology emerging as a result of nuclear reactors is that of heat transfer in liquid metals and in boiling-water systems. While



MTR Materials Testing Reactor, being made available to industry for irradiation service, has a universal coffin used to remove radioactive plugs and test specimens.

reactor engineers have been resourceful and inventive, they have not had to develop other basic new technology.

Confronting them also is the interesting problem of temperature and velocity distribution in a fluid film where heat generation occurs while the fluid flows through a duct or other container. Such a problem might be encountered, for example, in certain homogeneous reactors. And in such a system it seems theoretically possible to cause overheating of the container wall even in the absence of heat generation or transmission through it and in spite of the bulk liquid temperature being held to a safe level.

Some thermal-stress problems peculiar to situations where heat develops in a stressed member also arose and were solved. But on the whole, little original basic engineering technology has been developed. Indeed, an engineering student desiring to train for work in the field of nuclear energy would do well to choose his curriculum from among basic engineering fundamentals, leaving those peculiar to nuclear energy until later.

Controls and Instrumentation

To the uninitiated, the subject of reactor control can be interesting though sometimes slightly frightening. You might logically expect a number of unique probems to have arisen that would require new technological developments. Although a flood of new instruments for the detection, measurement, and control of nuclear radiation of various types has been developed recently, they are not basically new, with one exception: the scintillation counter in which the interaction of a quantum of radiation with a crystal or other material causes the emission of a flash of light in the visible spectrum. Indeed, many of the instruments use electronic circuits that were developed during World War II, without any subsequent improvement. The instrumentation field, however, has seen considerable improvement in the performance characteristics of available instruments, particularly in such characteristics as response time, dead time, and reliability. Also, many small improvements in certain features of operational convenience make today's instruments much better than those of the early days.

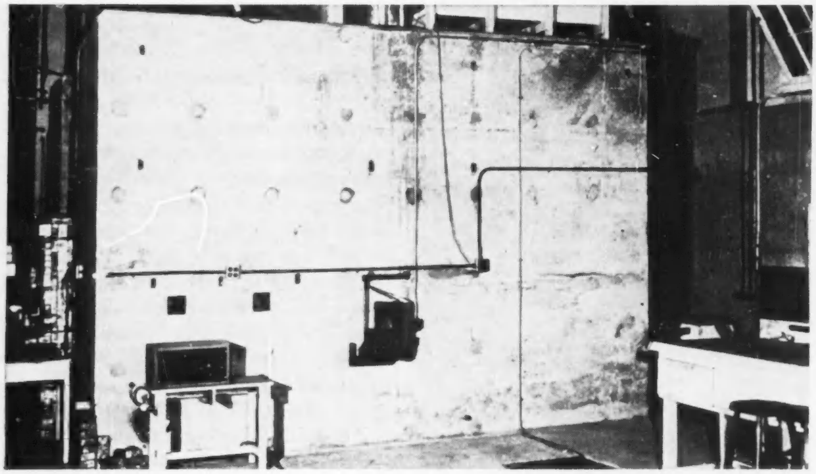
Probably the most significant single development in the field of reactor control was the one carried out in 1953 by the Argonne National Laboratory at the National Reactor Testing Station. For many years, and even prior to the first chain reaction, it had been suggested that a reactor which is both cooled and moderated by water could be made self-controlling if the water were allowed to boil. In such a system, if the reactor power starts to rise, the water boils more vigorously and naturally in the process of boiling a part of it becomes steam. Because this tends to reduce reactivity, it would hold the reactor power at a more or less constant level. For years this concept was discussed theoretically and rejected on the grounds that resultant fluctuations would make the reactor unstable.

In 1953 the Oak Ridge National Laboratory carried out a short series of experiments showing that, over a limited range of conditions at least, boiling did not produce divergent instability in the reactor. Later, the Argonne National Laboratory constructed a small water-moderated reactor and forced it to run away—intentionally increasing its reactivity abruptly and allowing the power to rise as high as it would. When the power had risen to a sufficiently high value, the boiling caused the steam to be ejected, and the reactor shut itself down without damage to fuel elements and without the release of fission products. In other experiments in this same apparatus, the reactor was allowed to boil steadily, producing steam much as a well-behaved boiler, thus exorcising the ghost of divergent instability that is due to boiling. But superstitions of this kind even in a business as new and presumably as free of tradition as reactor development will creep in.

Moreover, engineers are gradually becoming more sophisticated in evaluating the hazards attendant upon the operation of a reactor. The AEC has established an advisory committee on reactor safeguards to examine new reactor designs for their possible harmful effects on people or things in the vicinity of their installation. Such evaluations tend to err greatly on the side of conservatism. But more critical judgments are becoming possible all the time because, as the number of reactors have increased, there have been a very few unexpected power excursions, or surges. Never have they produced harmful effects beyond the immediate vicinity of the reactor, indicating that hazard-evaluation methods have been conservative.

Materials

The really significant technological advances that have been made in the nuclear energy field occurred in the general area of materials technology—chemistry, metallurgy, ceramics, and



THE WATER-BOILER REACTOR—INTRODUCED IN 1944—WAS THE FIRST HOMOGENEOUS REACTOR.

the effects of radiation on materials. This is not surprising, for customarily the engineer and the physicist first design a reactor and then complain bitterly if the materials man is unable to immediately supply materials of exactly the properties required.

Some of the major accomplishments in the materials field that resulted from the development of nuclear reactors include the examples that follow.

After several years of intensive reactor operation at Hanford, it appeared that it might be necessary to remove the reactors from service because of the harmful effects on reactor materials. This posed a serious and entirely new problem that was attacked with vigor, perseverance, and intelligence by GE's scientists and engineers at Hanford together with their colleagues at a number of other installations. Result: greatly prolonged lives of the reactors.

A thorny metallurgical problem arose in the early history of the Hanford reactors. The apparently simple and trivial operation of putting a protective aluminum can around the uranium slugs turned out to be the most difficult single technical problem encountered. Entirely new standards of reliability were found necessary. Consequently, many highly refined techniques were discovered, but no new basic technology was acquired.

The field of metallurgy yielded two more interesting examples. Shortly after World War II, beryllium was structurally one of the world's poorest materials. Brittle and nonuniform, it apparently could be worked only by grinding. Unfortunately, this operation produced powerfully toxic beryllium dust, and several near casualties resulted before necessary precautions were understood. In spite of these deficiencies, beryllium was destined to be an important reactor material. For this metal is an excellent moderator, having a low atomic weight, good scattering cross section, and small absorption cross section for neutrons. During a three-year period, beryllium was converted into a workable metal. And today it can be machined, forged, tapped, and handled in much the same way as the more common metals. Now, in addition to higher purity and uniformity, beryllium has increased mechanical strength and toughness.

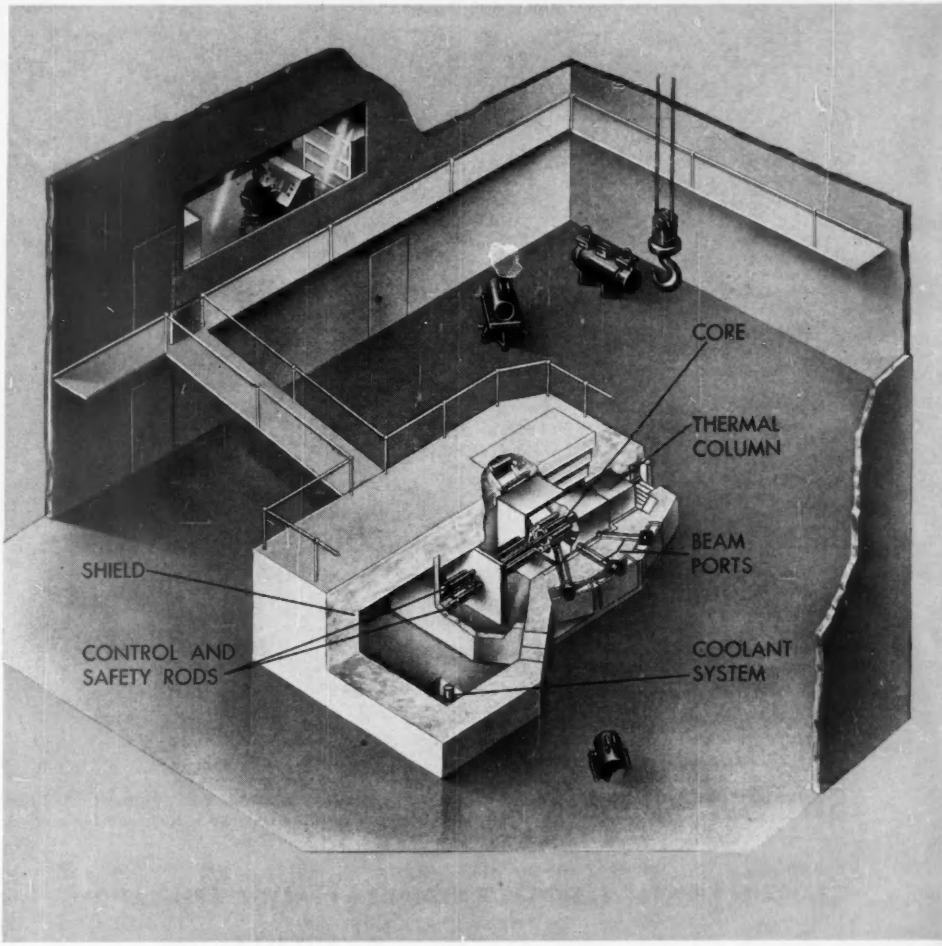
Zirconium—a metal of good corrosion resistance and excellent nuclear properties—seemed the favored material to use in the reactor of the STR program. However, zirconium as then produced contained a small percentage of hafnium that not only has a large neutron absorption cross section but also is extremely difficult to separate from zirconium. AEC contractors undertook this problem, quickly producing a hafnium-free zirconium of high quality.

The progress made in the handling of liquid metals can be cited as an example of successful materials technology. The liquid metals in general, and the alkali metals in particular, have superior heat-transfer properties. Other liquid metals, such as bismuth or lead-bismuth alloys, also have fine heat-transfer properties plus other characteristics that command the attention of reactor designers. However, the problem of containing these liquids, particularly at high temperatures, proved to be a substantial barrier to their direct use in reactors. Here again the chemists and metallurgists of the contractors associated with the AEC, foremost in the group being those at the Knolls Atomic Power Laboratory, attacked the problem. They learned that minute traces of various impurities caused corrosion of container materials for the alkali metals, particularly when accelerated enormously at high temperature. By painstaking removal of these impurities, the metals can be contained at high temperatures for extremely long periods. Concurrently, pumps of both moving rotor and magnetic types were developed for pumping liquid metals at high temperatures.

High-temperature materials in general have benefited greatly from the stimulus of the reactor development program. For example, a new brazing alloy suitable for joining various nickel-chromium-iron alloys does not contain boron, making it applicable to nuclear reactors. (The older and less satisfactory alloy contained boron.) This material, developed by GE's Aircraft Nuclear Propulsion Department, is finding use outside the reactor field.

It may be asked whether any new technology arose from work on radiation effects on such materials as lubricants, electric insulators, and elastomers. Sometimes, new products have resulted: crosslinked polyethylene owes its strength to irradiation after manufacture. Generally speaking, however, radiation-damage work has been confined to searching out those materials not adversely affected in large degree. Thus a substantial body of information is accumulating on the susceptibilities of different materials to various types and amounts of radiation, but this would hardly be called a new technology. Other instances can be cited: sometimes the addition of chemical inhibitors can reduce radiation damage to organic materials, but this seems to be the exception.

These are only the most obvious technological contributions of the initial period of development. And now the 1954 revisions of the Atomic Energy Act open the field for a more normal exercise of individual initiative, competition, inventiveness, and responsibility. In the years to come, these factors will be extremely valuable, materializing in increased research and development programs for the constructive use of atomic energy. Interesting and dramatic as the past years have been for a relative few, they will hardly compare with those of the future for all. Ω



Nuclear test reactor, originally designed at KAPL, is the only one of its kind. Of the solid-fuel water-cooled graphite-moderated type, it was designed for use as a precision industrial-process control device.

Nuclear Research Reactors

By DONALD ELDRED

During the past 20 years, many types of radiation equipment—x-ray generators, betatrons, synchrotrons, and cobalt sources—have been designed and built to produce nuclear radiations. Each machine has made unique contributions to science and will continue to advance the nuclear art.

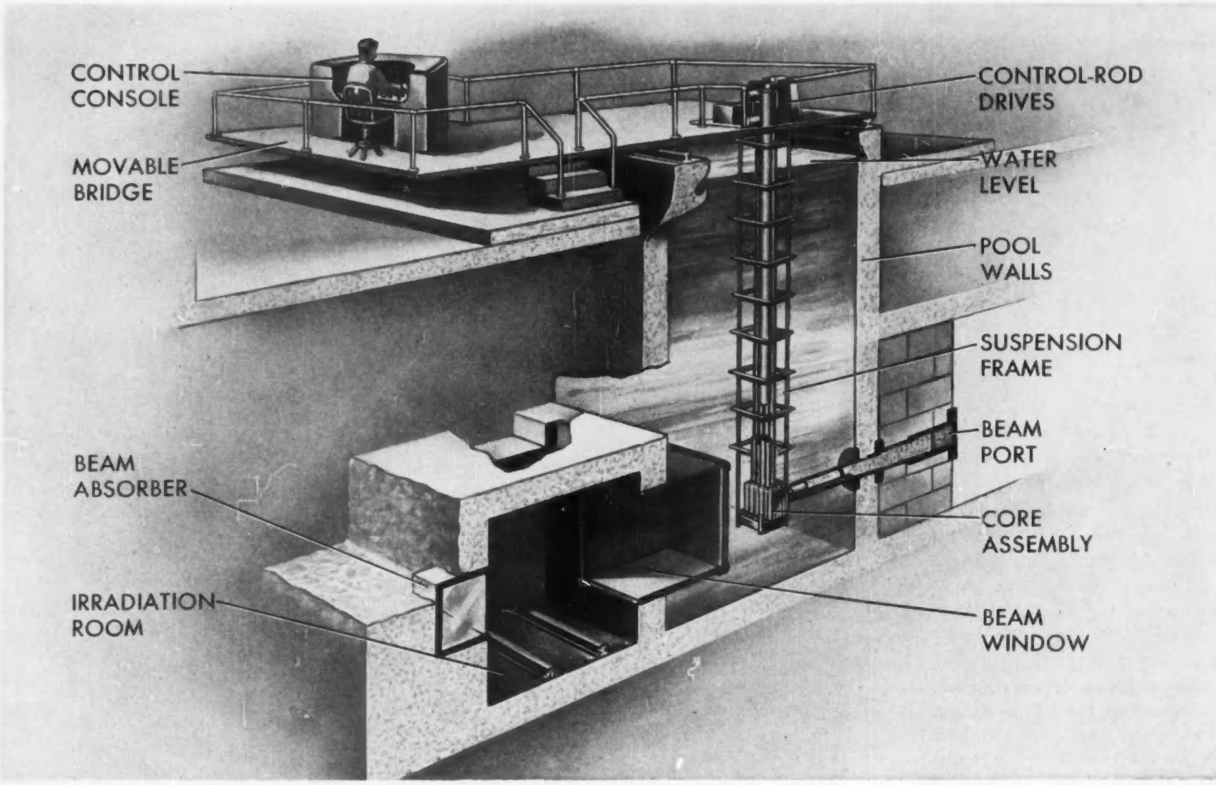
With the discovery of fission and a controlled chain reaction, new nuclear research tools became available. The construction and operation of many types of reactors for various applications followed. The first reactors produced plutonium. But since then, reactors have been designed for two main applications: production of electric power and general nuclear research. Many applications for research reactors exist in the basic sciences of physics, chemistry, medicine, metallurgy, and nuclear engineering. These reactors range in power from 1 watt to 15 megawatts, with proposed power levels of 175 megawatts.

All research reactors have stemmed from the AEC program. Fortunately, the Commission has encouraged the research-reactor program with both technical and financial backing. The resulting advancement of nuclear science might have been impossible without such AEC support. Future research reactors planned by the Commission will further aid nuclear development programs. Research reactors are but another important tool for science to use in research programs.

APPLICATION

Many other types of radiation sources, including particle accelerators and cobalt-60, are needed to carry out a complete nuclear development program. However, research reactors find application in many programs where conventional radiation machines cannot be used.

Research reactors supply a copious source of neutrons as well as a high gamma flux. In the use of these radiations, either independently or combined, reactors find their greatest application. Neutron fluxes up to 10^{14} neutrons per square centimeter per second can be



SWIMMING-POOL REACTOR —designed to produce large quantities of neutrons—appeals to universities and research organizations because it seems to have greater flexibility and utility than other types.

TABLE I—NEUTRON FLUXES FOR RESEARCH REACTOR APPLICATIONS

Application	Neutron Flux						
	10^8	10^9	10^{10}	10^{11}	10^{12}	10^{13}	10^{14}
Nuclear physics	x						
Absorption cross-section measurement	x						
Biological and medical research			x	x			
Activation of materials			x	x	x	x	
Neutron cancer therapy					x		
Neutron diffraction					x		
Fuel-element development					x	x	x
Radiation damage to metals							x
Study crystal structure					x		

produced with certain research reactors (Table I). Interest continues in raising neutron-flux levels to higher and higher values.

Gamma radiations from reactors can be used directly while the reactor is operating or independently by removing irradiated fuel elements. After their use in the reactor, the fuel elements provide a high source of gamma radiation. Such radiation finds use in chemical reactions, sterilization, food pasteurization, and biological and agricultural research.

Nuclear Engineering

Because research reactors are composed of the same types of components as power reactors, they can be used to train engineers in the nuclear engineering field. Such training includes studying controls, instrumentation, fuel elements, control rods, shielding, remote handling, coolant flow, and heat-transfer problems. Even operating experience can be obtained; and nuclear engineering problems—transit response, materials damage, shielding experiments, and power-removal tests—can be studied. Universities interested in a nuclear engineering program are considering a combined research and package-power reactor that produces low-quality steam for power or process use. Further research facilities such as neutron beam ports, thermal columns, and test holes are provided for nuclear research activity.

Physics

Research reactors have broad application in the field of physics, too. Neutron-diffraction studies offer a broad area of research involving the structure of molecules and crystals. Possessing wave properties, neutrons can be diffracted like x rays, but such diffraction differs from x rays in two important respects . . .

- Neutrons are scattered by light atoms, such as hydrogen, almost as easily as by heavy atoms; however, x rays are weakly scattered by light atoms.
- Neutrons have a magnetic moment and are scattered selectively by magnetic

atoms, but x rays are unaffected by them.

Because many types of materials are utilized in a reactor, it is important to know and understand the properties of materials that undergo neutron bombardment. One important characteristic is neutron cross section—the specific rate of interaction of slow neutrons with the atoms of a given material. Cross-section measurements permit wise selection of materials for a reactor.

Research reactors can produce short-lived isotopes that are helpful in all branches of research involving physics, chemistry, and medicine. Certain useful isotopes that have extremely short half-lives can be produced easily in a research reactor and immediately delivered to a physics or chemistry laboratory. Short transportation times preserve the intensity of the source.

Chemistry

Neutrons and gamma radiation can greatly affect chemical reactions. For instance, rubber can be vulcanized in a reactor. Radiations from a cobalt-60 source or an x-ray machine have produced remarkable changes in chemical properties. By using by-fission products from a research reactor, intense gamma rays can be made that produce varied chemical changes when applied to certain materials.

Admittedly, radiation sometimes degrades the properties of materials. However, new properties, such as resistance to high temperature, have often evolved. Some chemical reactions can be carried out equally well with any source of high-energy radiation. Certain sources other than reactors have inherent limitations, such as a small irradiation area of limited energy, that must be considered when choosing an irradiation source for chemical reactions.

Medical

For many years, nuclear radiations—such as x-ray machines, particle accelerators, and radium sources—have been used in medical therapy. Research reactors will probably offer another tool to the medical profession in the field of radiation therapy.

A national laboratory has conducted extensive cancer research using neutrons from reactors. In this application, boron-10 solution is injected into the blood and absorbed by cancerous tissue. While the boron remains in the cancer, a beam of neutrons is directed at it. When the neutrons are absorbed by the boron in the cancer, short-range alpha particles that destroy cancerous tissue are produced. Because results of these tests have not been conclusive, further research is being carried on.

Again, a research reactor can produce short-lived isotopes with certain radioactive characteristics that make them especially appealing to the medical field.

Mechanical and Metallurgical

A research reactor can be used to study all materials used in power reactors. Originally, the materials-testing reactor at the National Reactor Testing Station, Idaho Falls, Idaho, was designed to conduct materials research in the nuclear field. Although used extensively, this reactor has a backlog of proposed materials-testing work that will require additional reactors.

A major study must be made to find materials that will not only stand up under high irradiation exposures but also remain mechanically stable after years of gamma and neutron radiation. Much metallurgical work remains in the development of fuel elements that will have long life, good mechanical stability, and high resistance to corrosion. Here again, research reactors will be valuable.

Suitable containers are sought for corrosive fluids used by certain reactors. Programs involving these fluids must be carried out in the high neutron densities supplied by a research reactor.

In addition to these applications, nuclear research can be conducted in food processing, biology, and agriculture, as well as other major fields.

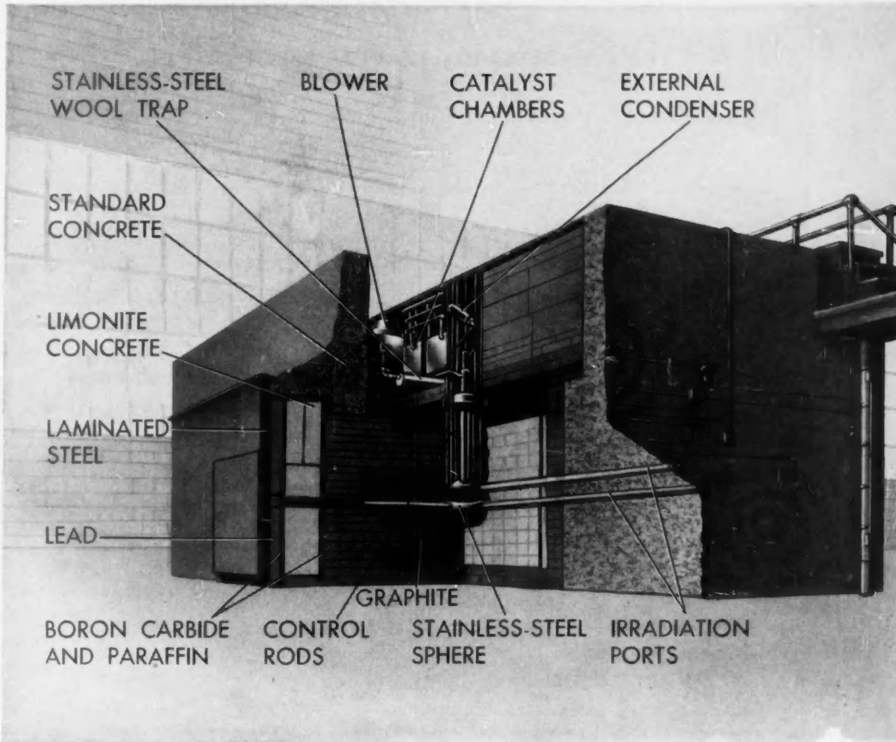
REACTOR TYPES

Four reactors show promise in the field of research. Each has certain advantages and disadvantages, depending on its final application.

Swimming Pool

The swimming-pool nuclear reactor (illustration, left) is a solid-fuel water-cooled and water-moderated research reactor designed to produce large quantities of neutrons.

The core of the reactor consists of a two-foot cube of fuel elements arranged to permit cold water to pass through the core. The water cools the reactor, absorbs dangerous radiations, and slows down the fast neutrons to a usable energy range. Located in the pool under



WATER-BOILER REACTOR —a homogeneous design—produces a sizable neutron flux with minimum fuel material.

TABLE II—RESEARCH REACTOR SPECIFICATIONS

Specification	Swimming Pool	Nuclear Test	Water Boiler	Heavy Water
Core size	2-foot cube	20- × 18-inch cylinder	1-foot sphere	2- × 2½-foot cylinder
Maximum power level	1000 kw	30 kw	50 kw	5000 kw
Maximum flux level	10^{13}N/(cm^2 sec)	10^{12}N/(cm^2 sec)	10^{12}N/(cm^2 sec)	10^{14}N/(cm^2 sec)
Fuel	Enriched U-235	Enriched U-235	Enriched uranyl nitrate	Enriched U-235
Fuel loading	3750 grams	2500 grams	900 grams	1900 grams
Coolant	Deionized water	Water	Water	Heavy water
Coolant flowrate	500 gpm	50 gpm	85 gpm	3000 gpm
Cooling systems	Integrated underwater primary systems	Primary loop	Secondary loop	Primary loop
Water purity	25 to 50 ppm	50 ppm	50 ppm	....
Shutdown sheets	None	6	None	None
Safety and coarse rods	3	6	3	4
Servo-type fine rods	1	1	1	1
Temperature	50 C	20 C	85 C	35 C
Proved power level	100 kw	2 kw	45 kw	1000 kw
Maximum flux area	24×24 inches	4-inch dia, 18-inch length	1-inch dia, 12-inch length	2½-foot dia, 2-foot length
Moderator	Water	Water	Uranyl nitrate	Heavy water
Reflector	Beryllium oxide or graphite	Graphite	Graphite	Heavy water

TABLE III—RESEARCH REACTOR FLEXIBILITY

Experiment	Swimming Pool	Nuclear Test	Water Boiler	Heavy Water
Simultaneous experiments	Excellent	Fair	Good	Excellent
Neutron diffraction	Excellent	Good	Good	Excellent
High local flux	Excellent	Excellent	Excellent	Excellent
High flux in large area	Excellent	Good	Fair	Excellent
Kilo curie gamma source	Excellent	Good	Good	Good
Bulk shielding	Excellent	Fair	Fair	Fair
Bulk sterilization (in foods)	Excellent	Excellent	Excellent	Excellent
Precise flux control	Good	Excellent	Good	Good
Fuel matrix studies	Excellent	Excellent		Fair
Isotope production	Excellent	Excellent	Excellent	Excellent
Animal exposure	Excellent	Good	Good	Good
Radiation damage studies	Excellent	Good	Good	Excellent
Neutrino detection	Excellent	Excellent	Excellent	Excellent
Neutron chopping	Excellent	Excellent	Excellent	Excellent
Equipment exposure	Excellent	Fair	Fair	Fair
Drug sterilization	Excellent	Excellent	Excellent	Excellent
Poison sensitivity	Fair	Excellent	Good	Fair
Foil activation studies	Excellent	Excellent	Excellent	Excellent
Malignancy studies	Good	Good	Good	Good
High power adaptation	Excellent	Good	Good	Excellent

Excellent (dark) Good (shaded) Fair (open)

approximately 20 feet of water, the core is held firmly by an aluminum suspension frame that is attached to a movable bridge framework. The bridge contains the control-system rods, drive motors, and auxiliary electronic equipment. Wheels permit its motion on rails that are mounted on the parapets of the pool.

Because of its higher flux possibilities, flexibility, and proved safety features, this reactor appeals to university personnel.

Nuclear Test

The nuclear test reactor—solid-fuel water-cooled graphite-moderated—was designed specifically for use as a precision industrial-process control device (illustration, page 27). Originally designed by KAPL, this reactor is the only one of its kind today.

Its special design permits a conservative power level of 30 kw to produce a flux level comparable with a 100-kw level of the swimming-pool reactor. The annular design of the core achieves this effect by producing a neutron multiplication of about 3 to 1 along the central axis of the core. At the 30-kw level, a small pump and heat exchanger are necessary to remove the internally generated heat. Control of the reactor is affected by the horizontal insertion of poison material along the periphery of the core.

Because of its small size and excellent potentiality for further increased power operation, this reactor will likely become a medical tool.

Water Boiler

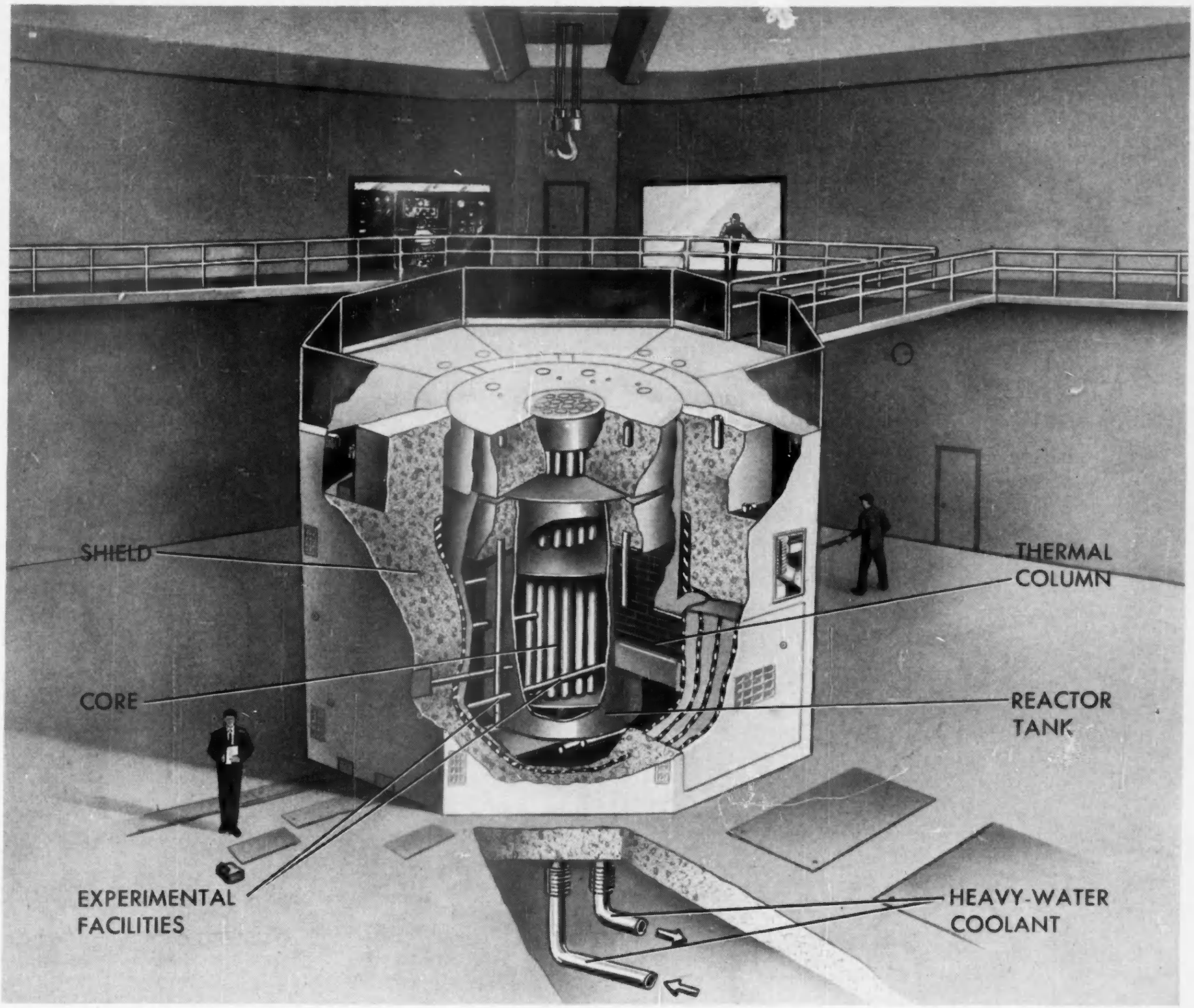
Designed to produce a sizable neutron flux with a minimum investment of fuel material, the water-boiler nuclear reactor (illustration, page 29) is of a low-power solution type.

The tested power level was established at 50 kw, with a thermal flux of about 10^{12} neutrons per square centimeter per second at its outer periphery. Because of the reactor's homogeneous design, radioactive gases are evolved during operation and are safely disposed of in a self-contained catalyzing and collecting system.

The boiler, or core, is located in the center of a four-foot cube of graphite, in turn surrounded by concrete, steel, and lead shielding to reduce the potent radiations to safe biological levels.

Heavy Water

The heavy-water research nuclear reactor (illustration) uses enriched



HEAVY-WATER REACTOR —cooled and moderated by heavy water—was designed as a high-flux reactor. Because of its broad experimental facilities, it is known as the most powerful type of research reactor.

U-235 as a solid fuel and is cooled and moderated by heavy water. Designed as a high-flux reactor, it has become known as the most powerful type of research reactor because of its extensive experimental facilities.

Two and one-half feet in diameter and two feet long, the core of the reactor is composed of fuel assemblies located in the center of a six-foot-diameter aluminum tank. This tank is filled with about 6½ feet of heavy water. Pumps send the heavy water through the core, and a heat exchanger limits the temperature rise. A massive concrete shield about 5 feet thick contains the entire assembly.

Four control rods resembling semaphore signal arms control the reactor and function as safety rods in an emergency. One servo-controlled fine rod serves as a regulating rod.

Specific Differences

A quick comparison of specifications for these basic research reactors (Table II) shows that . . .

- The water boiler has a fuel-loading capacity of only 900 grams, while the heavy-water reactor needs more than twice this amount.
- The heavy-water reactor needs 3000 gpm cooling water (heavy water), while the nuclear test reactor requires only 50 gpm. The heavy-water reactor costs considerably more than the swimming-pool type.

Comparing various research reactors (Table III), the swimming-pool type appears to offer greater flexibility and utility value to most universities and research organizations than the other types. However, depending on the application, each reactor offers its own unique features. For instance, the nuclear test reactor has a fine, precise control drive useful in certain physics experiments. The heavy-water reactor offers high flux values but at a much higher price.

As the use of research reactors spreads throughout industry and universities, more applications for research reactors will develop—each playing an important part in the long-range growth of the nuclear industry. Ω

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During his 16 years with GE, Mr. Eldred has had experience in control engineering and sales. Presently, he is Manager, Special Reactors and Component Sales, Atomic Power Equipment Department, Schenectady.


GENERAL ELECTRIC

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GENERAL ELECTRIC

Education for Nuclear Science and Engineering

By D. W. McLENEGAN

Five years ago Dean Thorndike Saville—then President of the American Society for Engineering Education (ASEE)—appointed several members from the major geographical regions as a committee to look into education in nuclear engineering. With the endorsement of the AEC, representatives from various AEC-sponsored operations joined this group to discuss the ingredients of nuclear science and technology as well as the relationships of these subjects to the established branches of engineering.

Some of the conclusions soon reached by this committee are still pertinent . . .

- The field of nuclear engineering stems directly from the physical and the life sciences.
- It crosses the boundaries of the recognized major branches of engineering, using the findings and practice of many older industries but always with reservations as to applicability of old data under new conditions.
- The magnitude of the individual projects calls for the exercise of sound economic as well as technical judgment.
- As in other large undertakings, major advances will necessitate pooling the contributions of many individuals having diversified skills; thus, to establish the precise communication, skill in human relations and in concise expression becomes extremely important.

Present Status in Colleges . . .

Today, nuclear engineering can be studied in many places—both academic and industrial. And the number of places where formal study can be combined with day-to-day engineering practice in this field continues to increase.

Experienced educators in the sciences and in engineering quickly and accurately identify the foundations of physics and chemistry that underlie nuclear engineering, the similarities and differences between this and other fields, and the specialized subjects to be added. Many colleges offer introductory survey courses, plus more comprehensive programs, particularly at graduate level.

Presently, all phases of engineering education are undergoing critical review, with increasing emphasis on rational analysis and on the fundamental approach for diagnosing and solving problems—a welcome trend to the nuclear industry as well as others facing complex engineering problems. Some of the new undergraduate curricula in engineering science provide an excellent springboard of the mathematics, physics, and chemistry required to attack the problems of nuclear engineering development.

With the rapid development of nuclear engineering, the colleges wisely concentrate on the subjects that can later serve their graduates as analytical tools. A nuclear engineer has been described as one having competence in a major branch of engineering, a perspective of related fields, and an understanding of the properties of matter in either stable or radioactive states. Thus his education in nuclear physics and chemistry should convey not only an understanding of the changes of structure and of chemical identity that occur in nuclear processes but also a grasp of the accompanying energy releases and the techniques by which these unusual identifications and measurements are made. All the basic engineering courses are within the young engineer's reach before he even enters the nuclear industry. And fortunately for him, these studies would be no less valuable should he choose another industry.

In both science and engineering, the benefits of the discipline of doctoral training need to be extended to more individuals. Specialization in complex problems is not the only objective. These men must also combine skill in analysis with vision to look beyond present methods and technology. To avoid becoming absorbed in immediate problems, nuclear science and engineering must foster the attitude of research and encourage the students who have vision.

At a few schools, a nuclear reactor is planned as an additional facility for instruction and research. One of the greatest values lies in clearly demonstrating the range encompassed by nuclear problems—a range so wide that engineers from all the major branches can participate. A variety of problems will flow to these institutions from the many industries with collateral interests in atomic energy, tracer techniques, or the use of irradiation to improve properties of materials. Today's graduate student participates in interesting workouts that his predecessors can experience only later in their careers, if at all.

A number of graduate programs now lead to the MS degree in nuclear engineering or related objectives. Characteristically, a careful groundwork of undergraduate preparation or initial graduate studies in science is laid before taking up specific nuclear technology. And the programs provide latitude to accommodate engineers whose undergraduate work has been in any of the long-established branches of engineering.

. . . and in Industry

The atomic power industry faces a somewhat different problem in offering post-college nuclear engineering education. To new graduates entering the field, it must offer opportunities for technical study and growth. It must also help more experienced engineers to adapt their diverse backgrounds of study and experience to bear on the problems of this new field. For part-time study, the "cafeteria" approach meets the requirements of both novice and experienced engineers. For example, in cooperation with Oregon State College, State College of Washington, University of Idaho, and University of Washington, GE conducts this program for their Hanford employees (Box, next page).

Offering a sufficient diversity of subjects to meet student needs, considering the number available and those willing to study, presents a major problem. Many of the recent graduates—particularly engineers—will want to strengthen their skills in technical analysis by further work in mathematics, physics, chemistry, and fundamental engineering subjects such as fluid mechanics. At the same time, engineers with more extensive background want more specialized studies such as nu-

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As Manager, Education and Training Section, Employee and Public Relations Department, Hanford Atomic Products Operation, Mr. McLenegan was responsible for operating the Company's Graduate School of Nuclear Engineering. With GE for 33 years, he is now Specialist—Design Engineering, Engineering Department, Hanford.

SCHOOL OF NUCLEAR ENGINEERING
General Electric Company
Richland, Washington

Summary of Graduate Courses

FALL	SPRING
Mathematics	
Differential Equations	Advanced Math for Engineers
Advanced Calculus	Complex Variables
Mathematical Statistics I	Mathematical Statistics II
Special Techniques of Analysis	
Numerical Analysis and Digital Computers	Analogs and Analog Computers
	Operations Research
Physics	
Modern Physics I	Modern Physics II
Nuclear Physics I	Reactor Physics I
Theoretical Physics I	Radiation and Shielding
Chemistry	
Physical Chemistry I	Physical Chemistry II
Inorganic Chemistry	Chemistry: Less Familiar Elements
Radiochemistry	Electrochemistry
Advanced Quantitative Analysis	Methods of Instrumental Analysis
	Colloid Chemistry
Engineering	
Fluid Mechanics	Heat Transmission
Engineering Metallurgy I	Heat-Power Cycles
Diffusional Processes I	Diffusional Processes II
Chem. Eng. Thermodynamics	Chemical Engineering Kinetics
Mechanical Vibrations	Strength of Materials (Advanced)
Electric Transmission Problems I	Electric Transmission Problems II
Advanced Physical Metallurgy	Problems in Reactor Design
Advanced Electronics	Servomechanisms
	Nuclear Metallurgy
Biology	
	Radiobiology

clear metallurgy or reactor design. Another group may pursue engineering economy and business administration—admittedly not nuclear engineering but pertinent to the problems confronting the atomic energy industry.

The courses in physical science continue year after year, symbolizing that competence in the sciences paves the way for engineering progress. Activity in engineering subjects usually reflects both the numbers of new graduates and the changing work interests of the more experienced. Subjects of direct value to the students in their work are chosen. And the effort has been made to avoid concentrating on standard practices that change so rapidly in a new and developing field. From this assortment, students formulate majors toward the MS degree in physical science or in conventional branches of engineering. A considerable number have attained this goal.

The ability to present classified data has been valuable as a means of illustrating specific proportions. But over-all experience indicates that even today nuclear engineering can be taught without extensive reference to classified material. A number of nuclear engineering textbooks have been published, with others in prospect. Papers presented before professional societies are rapidly enlarging the boundaries of information. Although the constants of a specific reactor may be classified, one can study the principles and problems of design and operation without encountering serious security limitations.

Where an industry is located close to a university, both the responsibility and the means for part-time study can be defined more readily. A wide choice of engineering and related studies can frequently be offered via the university curricula, with the industry adding specific job-related training to the engineer's work experience.

Need for Engineers

The Atomic Energy Act of 1954 has already stimulated industrial participation far beyond the earlier level. The need for nuclear engineers becomes apparent as industrial companies undertake comprehensive studies or specific nuclear developments. Many other companies are establishing a beachhead of technical understanding to investigate the outlets for their products or services in the nuclear field. The growth of this over-all industry must be forecast not only in dollars, plants, and kilowatts but also in the technical manpower required.

The substantial body of experienced engineers conversant with nuclear theory and practice can be augmented by some additions from other fields. But the nation's high demand for all kinds of experienced engineers indicates that most of the anticipated growth of the nuclear industry will have to be met by education and training planned years in advance.

Phases of Nuclear Engineering

The term "nuclear engineer" has generally been understood to describe engineers who conduct technical development and design. In so new a field, development naturally receives the most prominent attention. And the need for this function will continue to be a major one, for its importance can hardly be overestimated. But the transition from the initial phase to full-fledged industry will bring into prominence additional functions that should be considered in the educational planning (Box, next page).

These functions do not demand the same depth of technical understanding needed in engineering research and development. However, they will clarify the factors underlying the peculiar characteristics and problems of nuclear equipment essential to those who deal with atomic products or plants. For example, sales engineers in this industry will have to learn new concepts that are uncommon to other industries and that require thorough comprehension. Likewise, the engineer concerned with either installation, operation, or auxiliary power supply must understand clearly why energy liberation in a nuclear reactor cannot be turned off quickly and how to factor this knowledge into his planning. The supplier of auxiliaries must appreciate the nature of radiation damage to construction materials or to chemical reagents that are normally stable—a phenomenon perhaps entirely foreign to his experience. And the maintenance engineer who finds that access to hot areas is limited might well have to understand the concepts, measurements, and rules governing exposure to radiation.

Thus all facets of nuclear work involve some degree of understanding of changes in the structure of matter and of the corresponding energy releases and absorption. To some extent, then, the language must be understood by all the kinds of engineers who would work with these new forces. Toward this end, industry is helping its engineers according to their individual needs.

Colleges will probably need more time to judge the phases of nuclear training that they can offer the less technically inclined engineering students. Meanwhile, nuclear survey courses, already offered at many colleges, portray some of the problems and illustrate the technologies involved. As in other fields, the capabilities and preferences of the individual student will determine whether they should pursue nuclear study more intensively.

ADDITIONAL FUNCTIONAL AREAS OF NUCLEAR ENGINEERING

MANUFACTURING ENGINEERING—interpreting product designs in terms of the materials, tools, and process facilities needed to produce a product accurately and economically

SALES AND APPLICATION ENGINEERING—representing the product to the customer and matching its characteristics to the needs of the system and to the related equipment

INSTALLATION AND SERVICE ENGINEERING—putting a complex new product into service and analyzing and correcting troubles that may develop

OPERATIONS—supervising complex new plants in which the principles as well as the normal operating and maintenance must be understood

SPECIALTY MANUFACTURING—developing and producing new, perhaps unique, devices, components, or subassemblies; the application requirements must be fully appreciated by the engineers representing the suppliers of these specialties.

Special Fields

In addition to the recognized key studies, certain subjects not formally within the major fields of engineering contribute strongly to nuclear development.

Metallurgy stands out prominently in this respect. Added to the usual problems of strength, temperature suitability, surface protection, and cost are the aspects of nuclear suitability. These include the degree to which a metal transmits or obstructs various radiations, plus the duration and extent of the effect on the metal itself. This combination of nuclear and solid-state physics, chemistry, and conventional metallurgy has not yet attracted enough widespread attention and study, although it claims a high priority in the development of nuclear plants and equipment.

Another science—meteorology—increasingly contributes to the atomic field. Recently, much has been written regarding insurance against accidental release of radioactivity from nuclear plants located near densely populated areas. As more atomic energy plants are built, factors affecting distribution of air-borne radioactive wastes will need to be more thoroughly understood.

Radiation engineering—a composite subject—touches on biophysics, chemistry, and several branches of engineering. It deals with the measurement and shielding of radiation, techniques for decontamination, advance appraisal of plant designs as to radiological safety, and the establishment of operating practices to safeguard plant personnel. Today, industry is training radiation specialists to handle the growing demands for both developmental and operational work.

Nuclear engineers need comprehensive training in humanistic-social development. Communication, understanding, and co-operation are vital when individual projects cost many millions and require the interplay of social and physical sciences, engineering, and many craft skills. However, the problem is shared with other complex industries, the differences being in degree. As the nuclear industry progresses, one of its problems will involve achieving a balance of talents and interests to conduct activities of vast and interrelated technical, economic, and sociological potentials. And engineers equipped to meet these challenges will find many opportunities.

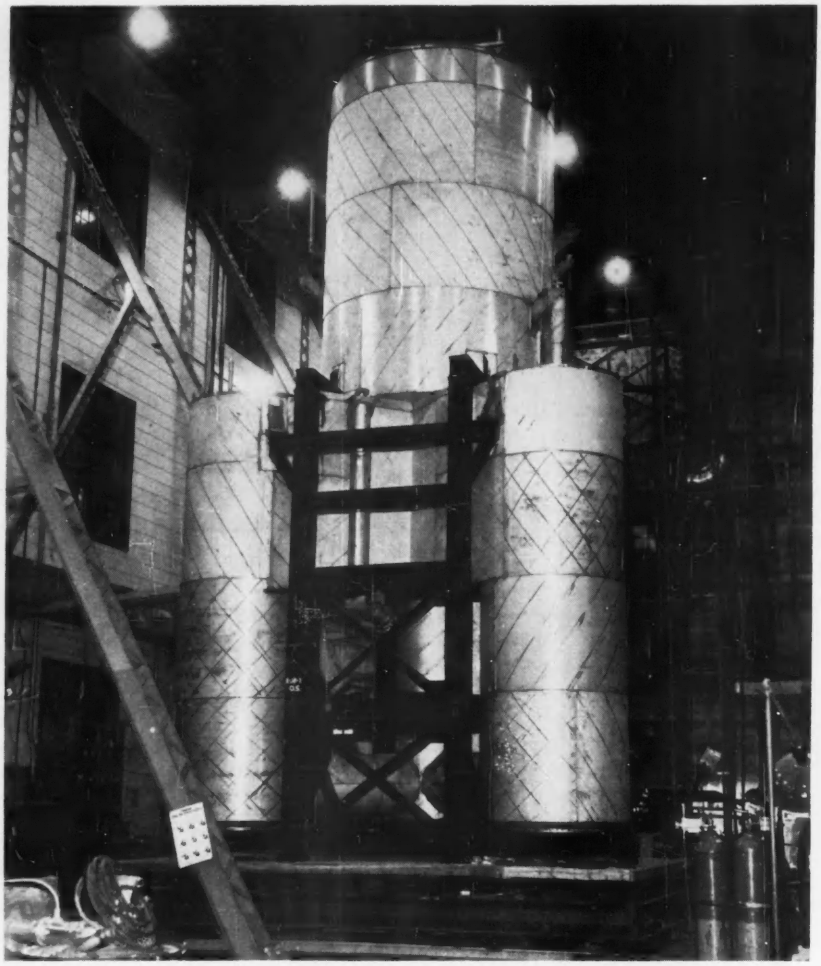
Beyond the specific technical problems lies a field of engineering economy of a new order of magnitude. Atomic energy is the only new source of energy that has reached the point of major commercial development during our lifetime. Through recent publications, the social and economic import of this development is just now being recognized. Having large-scale energy where chemical fuels are scarce is a new concept affecting not only regional but also international relationships. The welfare of large populations may be improved as energy can be made available from nuclear sources.

This is not exclusively the field of the engineer. But those who can combine economic vision with a grasp of the major technical problems may be able to exercise their skills in an almost worldwide area. This concept might well be portrayed to engineering college students as well as to recent graduates. Today's estimates indicate that this development will occur during their active careers.

Prospects

Despite all its problems, nuclear engineering should not be portrayed as something unique. Like all our other engineering, it is based on physics and chemistry; it differs only in the concept that matter sometimes departs from its stable state and that such departures are accompanied by unusual forms of energy emission. In most of its technical aspects, nuclear engineering education can be integrated with the present trends of engineering education, particularly that of more exacting problems analysis.

For some years to come, the urgent need for engineers who understand these special phenomena will create a special problem, although engineers with fundamental training can adapt themselves to this field—as many have already done. As the industry develops, the closest possible liaison with the universities will be important not only to industry, students, and universities but also to the national interest. Ω



STAINLESS STEEL USED IN THIS 40-TON VESSEL ILLUSTRATES THE APPLICATION OF . . .

Materials for Atomic Plants

By BLAIR R. ELDER

One of the easiest ways to learn about the atomic industry is to review the materials used in atomic plants and the criteria for their selection. This enables you not only to visualize the industry's present position but also to understand the necessary future developments to economically convert the energy release in atomic fission. The problems of finding adequate materials limit the design of an atomic plant. For materials often determine either the maximum temperature that an atomic reactor can attain or the feasibility of introducing a new product-recovery process. Further, product costs are lowered by materials that permit more efficient use of existing processes or the adoption of new, more efficient processes.

Initially, the problems of selecting materials for an atomic plant seem similar to those encountered by pumping, power, and chemical plants throughout industry. But you soon realize that the products of atomic fission—neutrons and radioisotopes that in turn produce alpha and beta particles and gamma rays—greatly complicate the normal industrial problems. The material-selecting problems have been more thoroughly investigated than the product problems—an area still requiring much research.

Because continuity of operation is critical and maintenance conditions difficult, a high degree of assurance of quality is essential.

To better understand the problems involved, let's take a functional tour of an atomic installation similar to the Hanford Atomic Products Operation. In such an operation, material usage can be divided into three categories: water plant, reactor plant, and separations plant. Carbon steel, cast iron, austenitic (300 series) stainless steel, and aluminum are the principal structural metals (photos). Graphite and concrete—both normal and heavy aggregate—are the principal structural nonmetals.

Selecting Materials for a Water Plant...

The water plant provides the atomic reactor with water of adequate quality to serve as a coolant for removing thermal energy produced by atomic fission. The water, taken from a river or other source, is purified, passed through the reactor, and returned to the source.

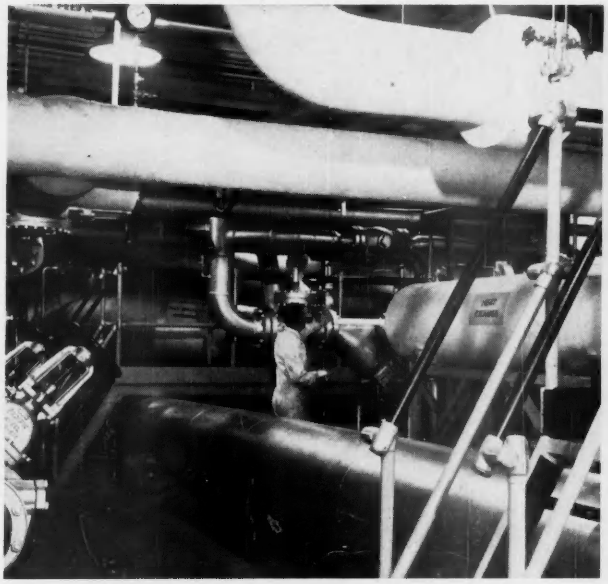
The criteria for selecting water-plant material correspond with those used in commercial water plants throughout industry, with three exceptions. The products of corrosion and water additives must not 1) contain material that will result in radioactive contamination of the water source; 2) contain elements that will cause an excessive loss of neutrons in the reactor; and 3) contain elements that will result in excessive film formation on fuel elements, with the attendant reduction of heat transfer. However, these factors are not of major importance in the system under discussion because the water is in the reactor for such a short period of time and the materials commonly used are generally compatible with atomic plant requirements. But in a recirculating system, where the same water is used over and over, these factors become a matter of great concern.

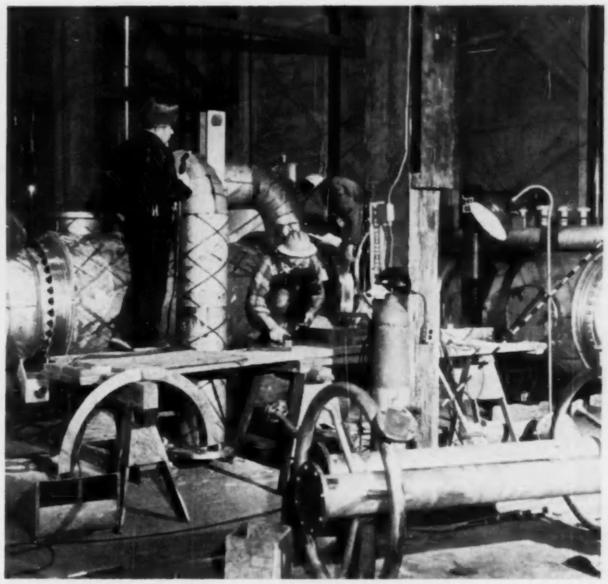
. . . Reactor Plant . . .

The function of a Hanford reactor is to produce plutonium—a man-made radioactive element—from natural uranium, principally composed of two isotopes: 99.3 percent U-238 and 0.7 percent U-235. The reactor must take neutrons emitted by the fission of U-235, slow them down to the thermal energy level, and promote the right amount of neutron capture in U-238.

Reactor-material quality must be assured, for failure of a critical component could result in the release of radioactive materials.

For the normal industrial power plant,





CARBON STEEL, CAST IRON, AUSTENITIC STAINLESS STEEL, AND ALUMINUM ARE THE MAIN STRUCTURAL METALS IN ATOMIC PLANTS.

corrosion resistance, physical and thermal properties, and ease of fabrication are considered in selecting materials. The selector of reactor materials for an atomic power plant must be governed by these criteria, plus many properties that relate to physics. A moderator—graphite, for example—must not only possess a low-capture cross section but also be of relatively low atomic weight so that neutrons will slow to the thermal-energy level in as short a distance as possible.

In general, reactor components other than controls must meet the low-capture cross-section requirements to conserve the neutrons for both the chain reaction and the desired reaction with U-238. Minute amounts of certain impurities with high-capture cross sections in reactor materials will render the material unusable. Control elements are deliberately selected for their large-capture cross section so that insertion of these units in a reactor will capture a large number of neutrons. The effective life of control material must also be considered; continued use, with resultant neutron capture, will cause burnout—reduction in capture cross section due to a reduction of the number of neutron-capturing atoms available to capture neutrons.

Aluminum and zirconium are excellent structural materials for use where neutrons are to be conserved. Boron, cadmium, and gadolinium qualify as excellent control materials.

PROBLEM: SELECTING MATERIALS FOR A REACTOR CONTROL ROD

Before choosing materials for a reactor control rod, you must realize that the rod will 1) be required to capture neutrons, 2) have a fluid present to remove heat resulting from the capture, and 3) be exposed to neutron flux during operation. Thus you must obtain neutron blackness (large cross section for thermal neutrons), corrosion resistance, good heat-transfer characteristics, and a short-half-life material or low-activity-after-irradiation material. Because the geometrical configuration should present a large area to neutrons, you must assume that the shape may be unusual and that ease of fabrication will be important.

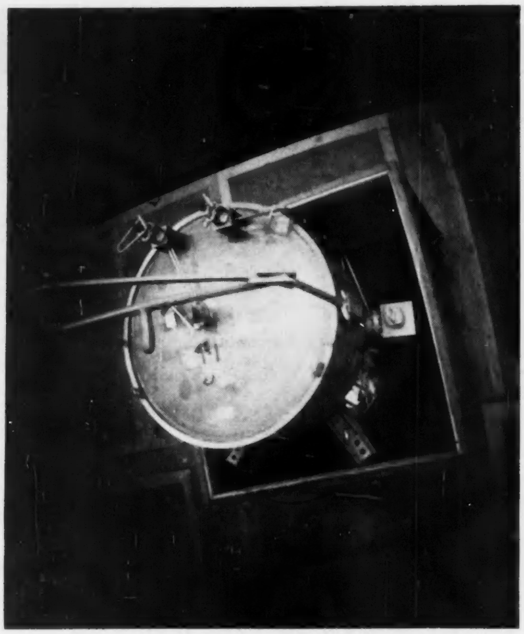
Your first thought may be to obtain a corrosion-resistant alloy of cadmium, boron, or gadolinium. You quickly reject gadolinium as rare and expensive only to find that the boron or cadmium alloys are not available. You now turn to a composite rod—corrosion-resistant covering, with control material inside. If the fluid is water, aluminum has the physical properties and corrosion resistance you're looking for. Certain aluminum alloys have a short half-life and can be easily fabricated; so you choose aluminum as the covering. Physics personnel help choose a neutron absorber. The type of radiation produced after neutron capture, the density, gas evolution, burnout, and other factors determine the choice of boron as the control material.

After a mechanical designer and a physicist produce an acceptable design, you should review fabrication methods. Then prepare a specification outlining the usual mechanical details and tolerances, testing methods, and alloy composition if a special alloy is required. Finally, issue an order for an experimental assembly.

These assemblies, or pilot plants, fill an important need by permitting investigation of radiation effects, materials in unprecedented service, and reliability.

Because radiation damage of reactor materials is such an important consideration, actual tests of the material are usually necessary to determine radiation effects on thermal and physical properties. Materials belonging to the same general class may behave differently when exposed to radiation. Some plastics become brittle, whereas others soften; some metals and semimetals grow in one dimension, contract in another, or suffer no change.

To protect equipment against radiation contamination, materials are se-



PERISCOPES GUIDE TECHNICIANS AS THEY REMOVE A FAILED VESSEL (RIGHT) FROM ITS WORK LOCATION BY REMOTELY CONTROLLED CRANE.

lected for minimum entrapment of radioactive materials and ease of cleaning. Special coatings on the exterior of some components also facilitate cleaning. Components that require replacement after exposure to radiation are constructed of short-half-life low-activity material to permit easy contact maintenance or replacement.

. . . and Separations Plant

In the separations plant, plutonium and depleted uranium are separated from other materials in the irradiated fuel. Generally, the fuel element is dissolved and various chemical processes carried out to accomplish the separation.

The frequent inability to examine failed equipment and determine the exact cause of failure may impair future material selection. Even the disposal of failed equipment becomes a costly problem; it must be buried with extreme care so that contamination is not spread and nobody is exposed to excess radiation.

The contamination of a separations plant by fission products introduces a complication that puts severer requirements on the selection of materials than in an ordinary chemical plant. For once the plant has been put into operation, the fission products make it more inaccessible to maintenance (photos).

Because this necessitates remote handling in the maintenance of piping and equipment—and even this is not always possible—there is a premium on long life of components.

Remote maintenance requires that equipment be built to close tolerances, thus adding to costs. High-quality materials are also costly. But these costs must be balanced against labor and downtime costs that are incurred in the replacement of equipment. On this basis, the higher material and fabrication costs are more than justified.

Extensive alterations are often made in vessel design so that a potentially weak component, such as a heating coil, can be removed and replaced remotely without loss of the entire unit. This would make the vessel far more expensive.

Of secondary consideration are damage to material by radiation—usually not appreciable—and process-stream contamination by corrosion products. However, gasket material and others of this type must be carefully screened to guard against potential contamination of plant product by materials that result from corrosion.

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With GE for five years, Mr. Elder is Metallurgical Engineer for both the Reactor Design and Development Unit and the Separations Design and Development Unit, Engineering Dept., Hanford Atomic Products Operation. He advises design engineers on metallurgical problems and investigates failures in plant construction and operations.

Typical materials for separations-plant service are types 304 extra-low carbon or 347 austenitic stainless steels. They must pass a corrosion test before use, and every precaution must be taken to assure that fabrication procedures are adequate, using reliable inspection techniques.

Other Criteria and Problems

Considerations common to material selection at atomic as well as other plants are availability of fabrication procedures to insure desired tolerances and compatibility of component parts in an assembly. Because field fabrication is often required, the differences between shop- and field-fabrication conditions should never be neglected in selecting a material. Further, the relative cost of completed assemblies of alternate materials must be compared.

After you have reviewed the economics and criteria involved in selecting a material, you may feel that your troubles are over. Actually, the hard part is just beginning. Now come the problems of transmitting your information to design engineers, selecting or preparing specifications for material and fabrication procedures, and achieving a realistic compromise between the ideal and the attainable. This final step is the most difficult because the minimum quality required for atomic work usually exceeds normal industrial standards.

Presently, American Society for Testing Materials (ASTM) or similar standards are used to the extent possible in material control. In unusual cases, new material standards are prepared for special fabrications and materials. In preparation of all standards, industry consultations insure that the requirements are not impractical.

Establishing the inspection and testing methods that assure the necessary quality are also important. The homogeneity of the material is difficult to determine, and many tests that give valuable information to trained personnel are unsuited for procuring material commercially because of hazy or nonnumerical results. For example, an etch test of steel—etching in acid to show structure—is widely accepted by materials people for determining cleanliness. Before this test becomes a standard for acceptance or rejection of stainless steel, the acceptable distribution, number, and size of inclusions or other flaws must be determined. Even the defining of a definite limit of what will or will not be harmful in service is difficult.

Of all the problems involved in obtaining adequate materials for atomic plants, writing accurate specifications is probably the most difficult.

TELESCOPES PERMIT THE VIEWING OF CONTAMINATED EQUIPMENT REQUIRING MAINTENANCE.

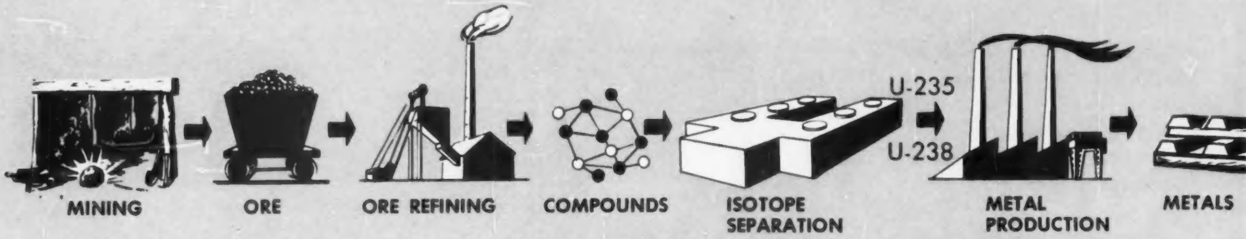
The Future

Much basic research has been done in the field of corrosion in atomic-plant process streams and the effect of atomic-fission products on materials—but more is needed. New materials in the reactor field, such as zirconium, offer improved properties; others, like titanium, offer superior corrosion resistance in separations plants. Development of information concerning these materials and the necessary standards for their application to atomic plants will result in reliability and economy.

Undoubtedly, power generated by atomic fission will place new demands on existing materials and create a need for improved alloys. And in the future, materials will continue to be limiting factors for reactor operations or for the introduction of new separations processes. In other applications, atomic plants may tend to use more common materials; for instance, carbon steel may replace stainless steel. Development of processes requiring less aggressive solutions may also allow the use of more common material.

The future will be busy for atomic materials people who will produce materials technology to aid in the development of the entire atomic energy field. Ω

LONG-HANDLED SOCKET WRENCH EXTENDS THE TIME A MECHANIC CAN SPEND ON REPAIR JOB.



DERIVING ELECTRIC POWER FROM THE ATOM INVOLVES COMPLEXITIES AND INDETERMINATE COSTS THAT COMBINE TO MAKE AN EXPENSIVE PROCESS. BUT THE INGENUITY OF INDUSTRY, TOGETHER WITH MODERN TECHNOLOGY, WILL MAKE ECONOMICAL PRODUCTION POSSIBLE IN THE FUTURE.

Fuel Reprocessing and Waste Disposal—

By W. N. MOBLEY

Despite the complexity and uncertain cost of deriving electric power from the atom (illustration), it is a foregone conclusion that we will learn to extract this energy economically—and we will do it in the foreseeable future.

The economics of future atomic power installations are broken down into three parts: fixed charges, operating costs, and fuel costs. In the area of fuel costs—including fuel reprocessing and waste disposal as well as the initial cost of the fuel—there is much promise for cost reduction. But this area also has problems—the majority completely alien to fossil-fuel plants.

Burn Up

At the present time, it's impossible to completely burn up all the fissionable material in a reactor's fuel elements before the elements must be replaced. In a recent survey, the Atomic Industrial Forum assumed that before 1960 a large central-station plant will burn some 35 percent of the uranium-235 fed into it before reloading and that after 1960 the fuel efficiency will be twice as great. Today's nuclear reactors, of course, burn up less fuel than the 1960 figure given.

For two reasons, fuel elements must be replaced before all the fissionable material in them is consumed. . .

- The fission process generates by-products; some gradually decrease the ability of the reactor to sustain a chain reaction, literally poisoning it.
- These same fission products cause physical deterioration and dimensional changes in the fuel element that bring about mechanical failure of the element long before other limitations apply.

Because fuel elements must be replaced before all the fissionable material in them is consumed, economical operation of any research- or power-reactor program demands that the unconsumed fissionable material be recovered from the spent fuel elements. (Possibly initial fuel costs will become so low in the future that throwing away spent fuel elements will be cheaper than reprocessing them.)

How often fuel elements must be replaced in a reactor depends on many factors. A large power-producing plant may have to be shut down as many as three times a year for partial replacement of fuel elements.

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Mr. Mobley—Plant Sub-Section Superintendent, Separations Section, Manufacturing Department, Hanford—joined General Electric in 1946 when the Company took over the Hanford Operation. He had been with the Operation two years previous to this time. Winner of a joint Coffin Award in 1951, he received this distinction for work in increasing the productive capacity of separations plants.

Reprocessing Problems

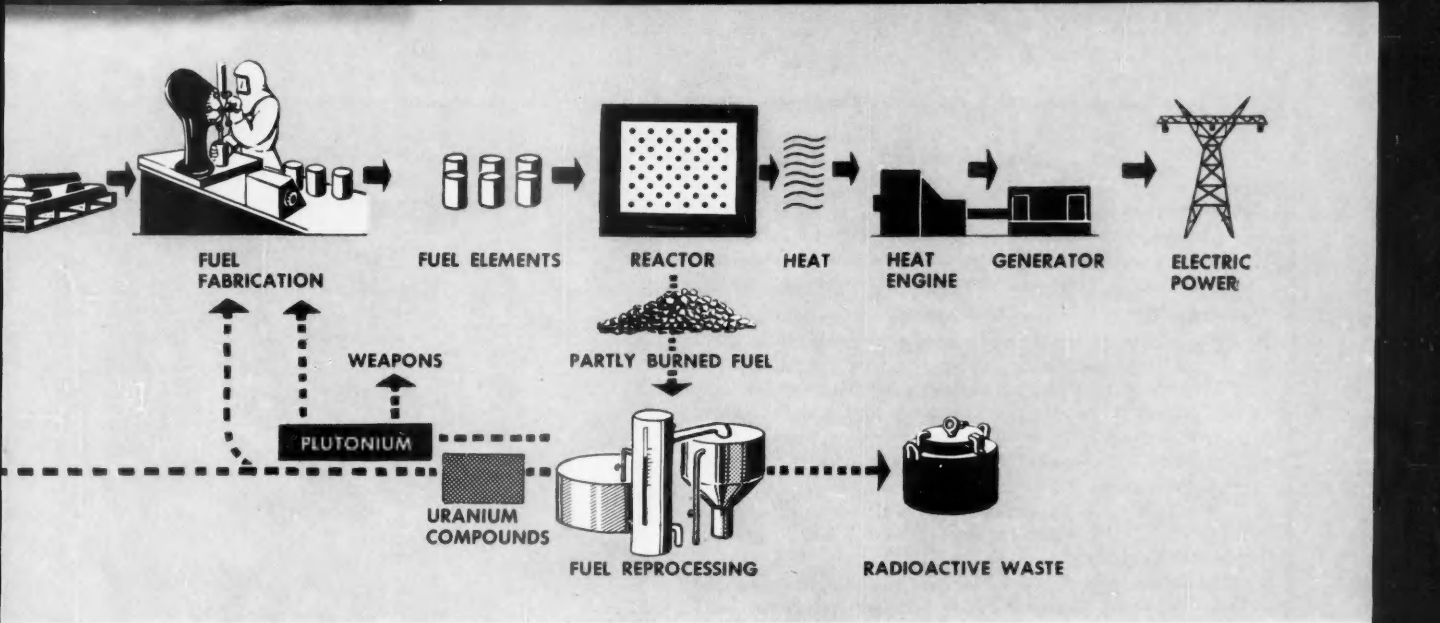
A recent AEC report, in discussing fuel processing, says, "The process is required to recover greater than 95 percent of the unconsumed uranium, produce a uranium product essentially free of plutonium, and reduce the fission-product activity to a level that will allow further processing of the uranium without shielding."

As a consequence of these stringent requirements, many reprocessing techniques have been investigated. One broad category includes such techniques as precipitation, solvent extraction, and ion exchange. Another group involves electrochemical techniques and heating the metal fuel and processing it in molten form.

The decision as to what particular techniques will be used for any particular reactor hinges on many factors—economic as well as technical.

At Hanford, the chemical processing of plutonium has been carried out over the past 10 years (Box, page 44). Although plutonium is involved, many of the same problems exist for any type of fuel processing. It will be interesting, therefore, to trace the progress of chemical processing at Hanford to see the challenges it offered and how the problems were solved.

From the beginning, plutonium separation was complicated by the usual problems of large-scale operation asso-



Roadblocks to Lower-Cost Atomic Power

ciated with the chemical industry, plus those of handling highly radioactive materials with their attendant hazards. The design of the original plutonium separations plants was still further complicated by the necessity of scaling up the production from a microchemical stage to full-size production plants.

The critical time factor of the war years intensified these earlier difficulties by requiring that the scaling-up operation be done concurrently with construction of the full-scale operating facilities.

Early Limiting Factors

Ten years ago, with the limited knowledge of radiation and its hazards, equipment was made as simple and foolproof as possible—even at the sacrifice of efficiency and operating economy—to insure adequate precautions for protecting personnel. Alternate routings for process flow and unusual provision for maintenance of equipment were essential measures. Thus the original design resulted in using a batch process and chemical precipitation methods for plutonium production. A review of the first plutonium plant might best be made by considering these factors individually: chemical process, equipment requirements, and waste disposal.

Chemical processing of the original separations plants had many restrictions. For instance, the control of critical mass—necessary to prevent nuclear reaction in process vessels—limited the maximum size of the batch that could be processed. Further, long hours of chemical reaction time were required for acceptable yields and for decontamination of the product. Decontamination requirements led to many time-consuming operations that had to be repeated cycle after cycle for desired results. Each process was allowed to approach equilibrium for maximum yields of an expensive, scarce product. These physical limitations on the productive capacity of the individual plant tended to tremendously increase the size of the plant required even for simple operations.

Equipment requirements associated with these chemical processing problems were many and proportionately varied. The highly radioactive nature of the process solution made it necessary to locate the processing equipment within heavy concrete cells. This in turn required that equipment be designed to permit remote operation and replacement. The extremely high radiation fields where much of the equipment was located warranted discarding rather than repairing failed equipment as a means for reducing radiation exposures. This maintenance philosophy led to the selection of simple, dependable equipment, such as steam jets for transferring process solutions. Individual operators stationed at each integrated unit of the cycle controlled all physical characteristics of the process—heating and cooling cycles, transfer, and feed rates. The moving equipment installed in the original design was limited to agitators for mixing the batches and to centrifuges for separating precipitates from the solutions. The mechanical components were built as ruggedly as feasible and generally gave a highly satisfactory performance.

The waste-disposal problem for atomic energy plants has plagued operating personnel since production was started. Every effluent stream from the process was highly radioactive and could not be released to the surrounding environment where it would affect the plant, animal, or fish life not only for the present but also for thousands of years in the future. Failed equipment and radioactive dust and gases posed the same problem. Again, the initial approach was an expensive one. Millions of gallons of waste produced each year in the plants were stored in underground steel-lined concrete tanks that cost approximately 40 cents a gallon to construct. Even slightly failed equipment was buried in underground pits—an extremely expensive recourse. Although considerable improvement has been made, such waste remains one of the biggest sources of chemical processing expense.

MAJOR STEPS IN PLUTONIUM PRODUCTION AT HANFORD

PREPARATION

Cylindrical uranium slugs—supplied by the AEC—are canned in aluminum jackets according to extremely exacting specifications to protect the uranium from corrosion.

IRRADIATION

Each reactor—a massive cube of graphite enclosed in a thick concrete and steel shielding as large as a five-story building—is pierced by hundreds of horizontal aluminum tubes. The uranium slugs are fed into these tubes by the thousands, in sufficient quantity to create a chain reaction. Cooling water is pumped past the slugs in the tubes at tens of thousands of gallons per minute.

Within the reactor, neutrons from the fissioning uranium isotope U-235 bombard the predominant U-238 to produce plutonium, Hanford's end product.

When discharged from the reactors, the irradiated slugs contain plutonium, fission products (a great variety of newly created isotopes), and much of the original uranium. The slugs are stored under water temporarily to permit partial decay of the radioactive fission products.

SEPARATION

Separating the plutonium from the irradiated slugs—probably the most difficult chemical problem ever undertaken on a large scale—takes place within intricate series of cells housed in huge concrete "canyon" buildings several hundred feet long and two-thirds underground. The cells contain the separations-process equipment.

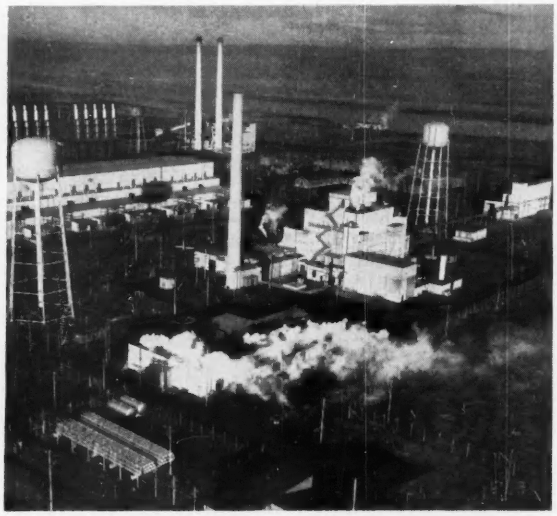
The plutonium must be removed from a mixture of uranium and radioactive forms of more than 40 different elements such as barium, iodine, cerium, arsenic, silver, tin, and cadmium. Radiation is still so intense that all work must be done remotely.

The irradiated slugs are deposited in a cell at one end of the canyon, where the aluminum jackets are dissolved in a solution. The solution is drained off, and the uranium, along with its plutonium and fission products, is dissolved in another reagent.

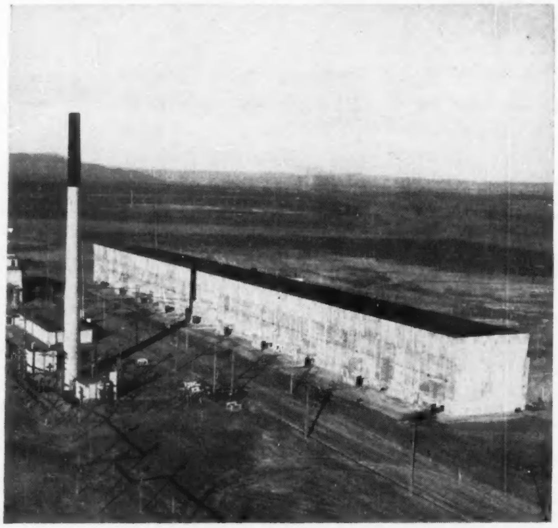
The process stream is pumped from one cell to another and subjected to a series of chemical treatments until separate solutions of plutonium and uranium, free from fission products, are obtained.

The plutonium is converted either into a slurry or into metal weapon parts and delivered to the AEC.

Reclaimed uranium is processed and returned to the AEC for reuse. Waste fission products are stored underground.



BY IRRADIATION, URANIUM IS TRANSMUTED INTO PLUTONIUM...



...THEN EXTRACTED FROM THE SLUGS IN "CANYON" BUILDINGS.

A Decade of Progress

To formulate a better concept of the present status of plutonium production and draw a few conclusions of its future direction, let's review the progress of the past decade. Although new technology plus added experience have improved the original plants, many basic limitations inherent in the equipment design restricted their scope.

The necessity for batch rather than continuous processing methods remained the principal limiting factor. New solvent-extraction processes that used modern automatic control systems were developed to circumvent this obstacle. These not only permit processing the radioactive materials on a continuous basis and at the same time recover the depleted fuel but also allow recovering and reusing a large amount of the process chemicals. The shortening of the long reaction times required in the precipitation process has materially contributed to the increased capacities possible with present-day chemical processing.

Changes in equipment designed for the new process, while still having to meet the needs for service life and remote operation, allowed the use of pumps instead of jets for solution transfer, plus automatic controllers for mixing process streams, temperature control, and feed rate control. Solvent-recovery systems were designed and installed—safe from the standpoint of critical mass control. New decontamination techniques and remote-maintenance methods permitted repair of the equipment if it failed. Centralized operating controls required fewer personnel. This progress has resulted in lower cost and more efficient operation, and the future holds still greater improvements.

Growing Disposal Problems

Waste disposal has been studied from every angle because of its excessive cost. Reduction in storage space has resulted through development of chemical scavengers that precipitate the radioactive materials and permit less costly disposal of the relatively inactive effluent. Heat generated from the radioactive products—up to four watts per gallon—is sufficient to boil the waste solutions and permit removal of water vapor. This heat results as the wastes absorb their own radiation, converting the energy of the rays to heat. Although this system is not yet fully exploited, only the solids remaining after concentration of the salt solution will eventually need storing. But already, permanent storage costs are less than 25 cents a gallon. Further improvement may yet be made by reduction of the salt content of the waste streams.

Nature assists Hanford in saving millions of dollars on expensive storage of radioactive waste. Sometimes, millions of gallons of residue from the processing plants are carefully dumped into the ground to filter slowly through hundreds of feet of soil, gravel, rock, and clay.

Hanford plants were built on layers of sand and gravel that lie in a huge saucer of impervious volcanic rock. The region has not only a low annual rainfall but also a deep water table with a relatively low gradient—nearly perfect conditions for disposing of the radioactive wastes.

The desert soil traps most of the radioactive wastes, partly by soaking them up and partly by chemically uniting with some of the ray-emitting elements. The water table lies in sediments more than 300 feet beneath the Hanford plants.

Predictions indicate that it will take many years for the waste material to reach the Columbia River about 10 miles away to the east, and by that time its radioactivity will have diminished far below maximum safety levels. Much will never reach the river, some only after many centuries.

Preliminary laboratory experiments, together with never-ending studies, assure that liquids and radioactive materials migrate underground at the predicted rate.

Even after the radioactive materials are interred in the desert wastelands, water samples are taken from test wells drilled near the disposal facilities to determine the distribution of the radioisotopes.

As more electric power is generated from the atom, the waste-disposal problem will grow in magnitude—perhaps to staggering proportions. By 1964, the volume of hot sewage handled annually in the United States may reach 60-million gallons; by 2000 AD, the figure may jump to an appalling 250,000 gallons daily. And the world's daily flow will probably be 10 times that figure.

Some scientists advocate using the sea as a bottomless cesspool. Both Great Britain and the United States dump some of their less virulent waste products in the Atlantic. But Dr. Roger Revelle, director of the Scripps Institution of Oceanography at La Jolla, Calif., has said: "I would be prepared to turn my back on the sea for all time as a food source if I thought that marine dumping constituted even a mild threat to the future well-being of mankind.

"At the moment we know almost nothing about the long-term genetic effects of radiation on future generations. And we know little more about what goes on in the depths of the oceans."

Other techniques have been mentioned as possibilities for disposing of fission wastes . . .

- Pumping into abandoned caves, mines, or oil wells
- Blending into slugs of concrete or clay
- Dumping in desert or arctic regions
- Firing by rocket to the moon or some other extraterrestrial graveyard.

But the picture is not entirely bleak. Waste products contain some radioactive materials that could be put to work as sources of radioactivity in medical work, for the preservation of food and polymerization of plastics, and as tracers in industry and agriculture—provided that the complex mixture could be separated.

One suggested method for separating individual radioactive isotopes involves extracting the mixture with various solvents to remove them either as groups or one by one. Another method is the use of the ion-exchange process. Both promise the production of quantities of various isotopes that when marketed—along with certain rare metals also extracted—could help reduce the costs of fuel processing.

Looking into the Future

Progress will continue in the chemical separation of atomic products, particularly in more economical production and in the recovery of spent fuel elements. Contributing factors will be . . .

- Further automation of the operating plants
- Improved equipment reliability
- Additional recovery and reuse of process chemicals
- Further concentration, recovery, and use of the radioactive by-products
- Improved decontamination and, therefore, reuse of failed equipment.

Exact arrangements for purchasing fuel by atomic power producers are nebulous. Until such time as a far higher percentage of fuel can be burned up before discharging from the reactor, probably the sale of fuel will be from a central source that in turn would buy spent fuel from the power producers. This central source would have separations plants of great enough productive capacity to service a large number of power-reducing reactors at lower unit cost than with individual separations plants.

Regardless of the final arrangements, knowledge and experience gained over the past decade in the chemical processing of plutonium will bring even closer the day when electricity generated by heat from the atom will flow in ever-increasing quantities through the transmission lines of America. Ω

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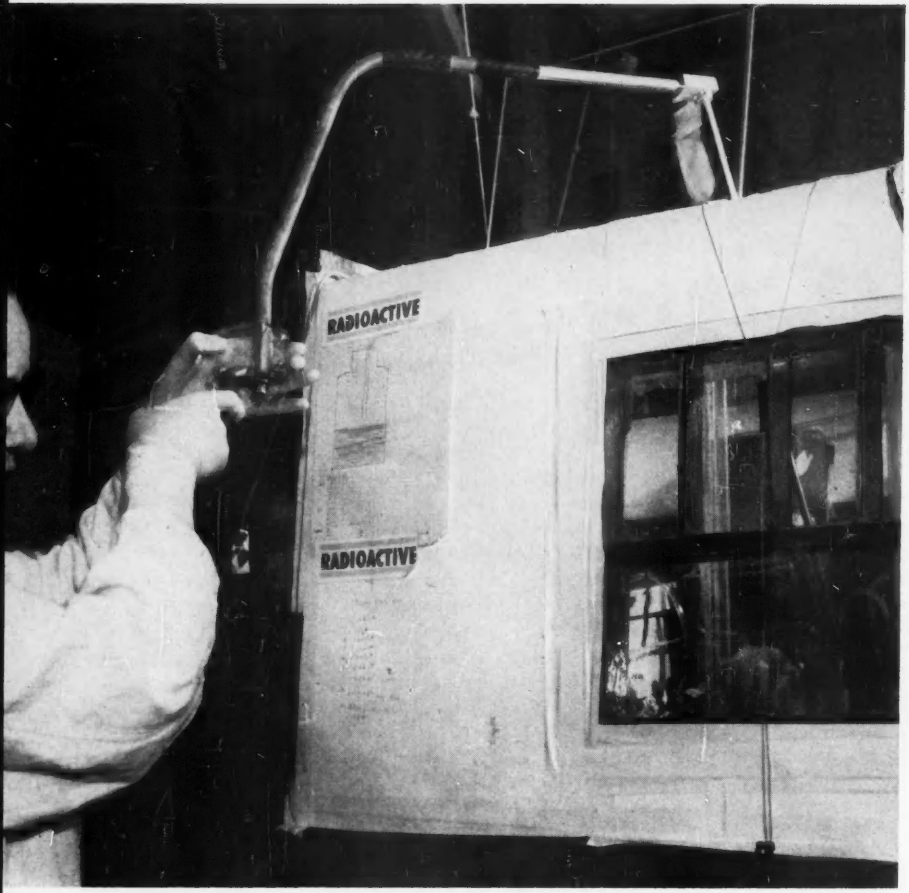


HANDLING RADIOACTIVE MATERIALS BEHIND BARRICADES INSURES PERSONAL SAFETY.

Handling Radioactive Materials

By E. HOLLISTER
C. D. CARROLL
D. T. BARRY

The industrial age is tied inseparably to conveying, transporting, and packaging products that run the gamut from the hand truck to the vibrating conveyor; from the forge-shop tongs to the traveling crane; from the pharmaceutical-capsule filler to the bottling machines. Human hands are neither fast enough, nor strong enough, nor frequently safe enough to transport, transfer, measure, and package materials at a rate equal to production.

The handling of radioactive materials plays a major role at any atomic energy installation. It must be done not only economically and efficiently but also with great care to insure personal safety—the foremost problem (photo). People must be protected and materials safeguarded from loss, contamination, and breakage.

As recent as 20 years ago, human life was greatly in danger, for injuries from the misuse of radium and x rays were much too frequent. Radium radiations were recognized as extremely valuable, and experimental work revealed its possibilities but not without the loss of some of our nation's technicians. Fortunately, more plentiful sources of radiation have replaced expensive radium. Their development, together with additional experimental work, necessitated a new approach in the handling field, based on a philosophy keyed to these needs.

Radiology finds numerous applications in industry: The petroleum people use radioisotopes in pipelines to indicate product flow; the sheet industry, both metal and nonmetal, to check thickness; the agriculture and soil-conservation people to study plant growth and mineral effects; the hospital and research laboratories to discover the answer to body malfunctions and to correct or limit harmful cell growth and conditions; and the atomic energy scientists and engineers to develop civilian applications and make new discoveries.

Equipment

Several important types of equipment are absolutely necessary to make this new science safe, practical, and basically successful. This article won't cover radiation measuring instruments, or monitors—a complete field of its own and one closely allied to handling. In fact, monitoring alone allows the job to be done intelligently. Other necessary and related lines not covered here are radiation shielding, viewing systems, ventilation, and waste disposal.

Let's first consider equipment—casks, dollies, traveling hoists, and tools—used for transporting material. Casks hold liquids or solids for removal between required points near or far to provide adequate shielding at all times.

•

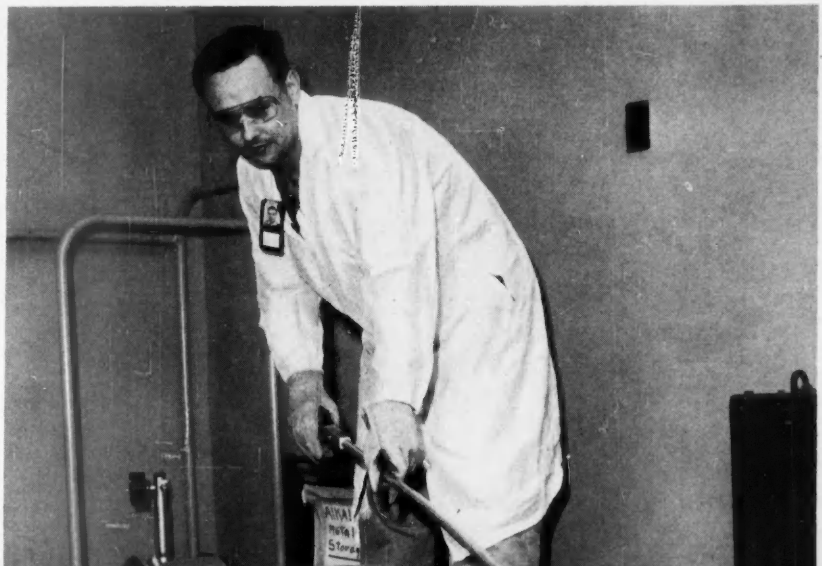
Mr. Hollister—Mechanical Engineer, Design Section, Mechanical Development Unit, Hanford—has been associated with General Electric since 1950. He is responsible for the design of special equipment for the improvement of production operations. Both Mr. Carroll and Mr. Barry joined General Electric on the Test Course and are presently with ANP. Mr. Carroll, with the Company since 1946, is Lead Engineer, Methods Engineering at ANP's Idaho Test Station, Idaho Falls, where he is concerned with the application of remote-handling equipment to ANP power plants. Mr. Barry—Engineer, Experimental Mechanical Engineering Unit, ANP, at Evendale—conducts experimental and development investigations for the remote handling of ANP power plants. He has been with General Electric since 1951.

HANDLING EQUIPMENT PERMITS POURING AND MIXING OF HOT SAMPLES AND MEASURES A RADIOACTIVE SAMPLE WITH A REMOTE PIPETTE.

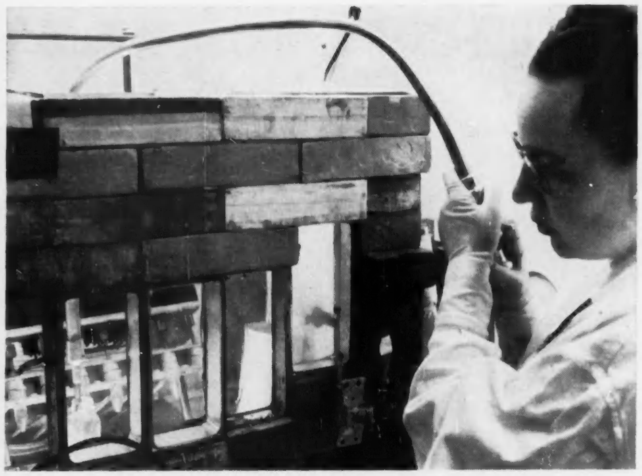
Dollies for carrying the casks outside a cell or secondary containers inside are either floor- or rail-mounted and operated directly or remotely. Traveling hoists for the same purpose are operated in a similar manner but mounted on overhead rails. A cell describes an enclosed area where radioactive materials are sufficiently shielded to protect operators working on the outside.

Another group of equipment includes tools—tweezers, tongs, holders, and manipulators—for handling materials and equipment behind barriers and inside such shielded areas as cells, hoods, and caves. The manipulators range in size from the hand-held variety to the wall-supported or the remote-controller unit mounted on a traveling dolly. They are used to transfer vessels such as centrifuge cones, filters, flasks, and pipettes from one position to another in a chemical process or to move samples and equipment around for the physical testing procedures of metallurgy. These tools help in positioning items for the various steps of the operation or for making observations. The numerous manipulating functions of adjusting clamps, turning valves, moving dollies, and adjusting viewers and other equipment must also be carried out.

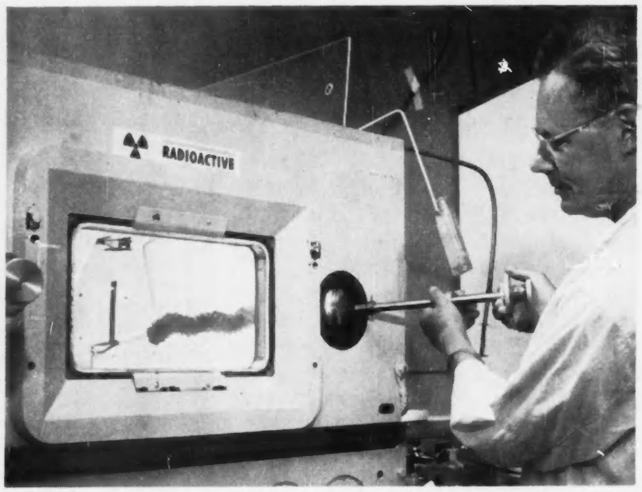
Further, handling equipment measures radioactive samples by pipetting (photo, top right) or weighing for titrating; determines *p*H values and specific gravity; and analyzes spectrographic or



NESTED CASKS PROTECT TRANSPORTATION PERSONNEL AGAINST ANY UNDESIRABLE RADIATION.



TONGS—here a two-cable control between handle and working ends—are the fundamental tool to grip, lift, and move radioactive items.



COMPLEX O-MAN—because of its versatility and delicate rate control—is known as a general-purpose manipulator.

FLEXIBLE BOOT of a through-wall tool prevents contaminants from being carried to the outside as the arm is pulled through the wall.

metallographic procedures. Stirring (photo, left, page 47) filtering, evaporating, and centrifugation also require tools instead of hands.

All the equipment used in handling radioactive materials must do the job efficiently, without hampering the success of the work. Awkward entrance or transfer of the sample not only consumes time but also increases the possibility of spillage or breakage. Thermometers, heaters, stirrers, syringes, and miscellaneous vessels require the freedom of motion appropriate to their use, always in a minimum space. A manipulator usually reduces 25 hand movements to 7 mechanical motions.

An analysis of handling equipment in detail will further point out problems and special features that must be met in this field. You will see from a review of the design and use of these tools that handling radioactive materials was a difficult problem before such tools were available, but now the procedure is likely to become as commonplace as handling the casting operations of a foundry.

Casks

Continually repeated process sampling for production control requires a single-purpose cask, consisting of a welded mild steel shell enclosing an inner liner of stainless steel. Lead, cast in place, fills the intermediate space between shell and liner. Tube connections adapted to quick connect and disconnect extend through the lead shielding. A protective cover locks or seals the tube openings against unauthorized entrance and leakage of contamination. An auxiliary vacuum system adds or removes the sample liquid directly to or from the inner liner.

A common type of cask is a shell filled with lead having a cavity bored in the center and covered with a lead-filled cap. The cavity holds a bottle, flask, centrifuge cone, or the vessel required. The thickness of the lead depends on the radioactivity of the sample. When used for shipping, such a cask would have the vessel packed in tightly and the cover bolted or fastened securely.

A cask of flexible design is composed of several sections that can be nested (photo, lower, page 47) to protect against any undesirable radiation when handled by personnel of a commercial transfer business, for instance. One cask might be sufficient if its use were confined to the laboratory. These exposures, however, would be extremely undesirable for an extended period.

Another economical type of cask—a glass vessel in a covered container made of compacted concrete—carries lower activity radioisotope solution. Both container and cover are placed in a tin can and sealed by crimping on the top.

When activity is at a medium level, solid steel casks in contrast to lead-filled casks are equally suitable for handling these radioactive materials. For high-level radioactivity, such shielding would result in a cask so large that it would be too awkward and too expensive. This points up the need for analyzing a shielding problem with respect to materials. Shielding ability of a material is approximately a direct function of its density; mercury, gold, and tungsten would be superior to lead for certain applications but impractical economically.

Various provisions for transporting are possible. Whether trunnions at the sides, holes in the sides, or a bail in a locking cover, they should be arranged for pickup by crane hook or sling. A cask and dolly may be built as a mobile floor-mounted unit, such as a horizontal cylindrical cask supported in a cradle on hard-rubber swivel casters. Smaller casks stand on the floor or on a pallet to be carried by a lift truck.

HOW DESIGN INFLUENCES CHOICE OF MANIPULATORS

Let's say that a nuclear reactor for a stationary electric power plant discharges its burned-out fuel in the form of eggs that must be reprocessed by remote control back into granular-like fuel for the reactor. They must be broken; the shells thrown away; and certain elements separated, mixed with other ingredients, and baked.

Any company in the food-processing industry, for example, would consider this a straightforward design problem and order suitable machinery for fast, efficient processing. But the reactor application would need much more reliable machinery than normal industrial equipment. For instance, if the first machine started dropping eggs, it could not be approached to be repaired manually as it would have contaminated itself with the highly radioactive eggs. It would have to be removed and replaced or repaired remotely, suggesting a backup installation of general-purpose remote-handling equipment.

Although the entire reprocessing problem could be handled by general-purpose manipulators, it would mean that the individual operations would be manually controlled and as such would probably be slower. But consider this advantage: Suppose that the engineers responsible for operating the reactor discover a way to increase the power output by supplying it with a different fuel so that the reactor now discharges square eggs. General-purpose equipment would require only a small tooling change to accommodate the new square eggs, whereas with special-purpose tools, the whole set of machinery would have to be replaced.

The over-all costs and probabilities of change will govern the choice of the machinery installed at this or any other reactor.

Tools . . .

Of the many tools in existence, only a few of the representative ones will be described. Scientists and engineers all over the country have met each individual problem in their own way. Closer contacts and wider circulation of information have resulted in successful efforts to standardize and reduce costs.

Tongs are the fundamental type of tool to grip, lift, and move items. At times, the cask cover must be removed, the container lifted out, its stopper removed, and a sample decanted—all requiring long-handled tongs. A practical system is a two-cable control in an extension supporting tube between the handle and working ends (photo, top right). Hand closing with spring opening allows feel of the gripping force at the hand. When the tube is straight, a push rod can be used for transmitting the motion. A hydraulic system, arranged with a pistol-grip handle and a trigger-type operation, has proved successful.

With this type of tool, distance provides protection. It can be used to operate through a ball-and-socket support in a shielding wall (photo, lower right). A flexible boot over the arm inside the wall prevents contaminants from being carried to the outside as the arm is pulled through the wall. If the arm is bent in a U-shape, the tongs can be used over a shielding wall; a flexible cable would be substituted for a rigid push rod.

Each of these manipulators would carry gripping fingers designed for either a general or specific purpose. A practical design has interchangeable jaws.

Another elementary type of tool is an extension wrench with a socket, hook, or other adaptation to the work. This unit can turn valve handles, adjust clamps, turn switches, or lift equipment by a ring or bail. The design can be made with a solid shaft for a straight arm or flexible shaft for a bent arm.

When these tools are used through or over a wall, the simple gripping or turning actions usually do not allow sufficient freedom at the working end to make the necessary motions. The bending motion at the wrist, as well as rotation of the working end, compensates for the angular position of the arm. Often, a vessel of liquid must be held exactly level to avoid spillage or to correctly locate it. Complexity of design enters at this point, necessitating ingenuity in the use of mechanical components: gears for direction and torque change and chains, sprockets, tapes, cables, and pulleys for transmission; antifriction bearings, weight-saving materials, and counterbalancing.

. . . and Manipulators

The more complicated hand operations require manipulators. Their development for remote-handling facilities has progressed from the early simple mechanical devices designed for specific tasks to more versatile complex machines such as GE's O-Man (photo, left). Because of the versatility of these complex devices, they have become known as general-purpose manipulators.

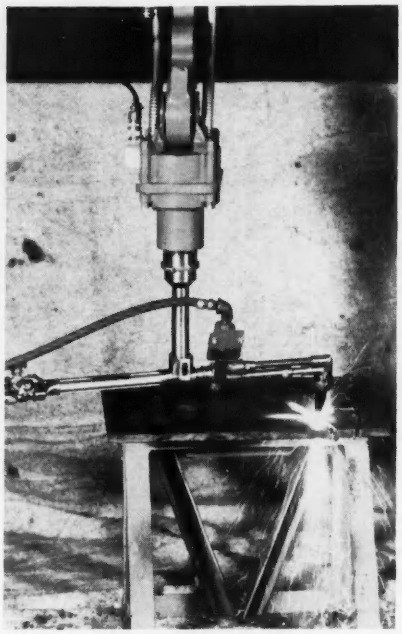
From the development of the first simple devices came the more complex, though still single-purpose machines, known as special-purpose manipulators.

Careful analysis of the economics of each installation is required before making the choice between special- or general-purpose equipment. Consideration should be given to another factor: should the manipulator be fitted to the task or vice versa? With the constant threat of obsolescence in this rapidly advancing field, general-purpose manipulators are becoming generally recognized as the soundest investment (Box).

Essentially mechanical arms, those built to date can be classified by the method of their control: rate controlled and master-slave controlled.

Rate-controlled manipulators have individual motor-driven arm parts controlled from a control box, or console. By moving control handles at the console, the operator controls the motion

PIPETTE measures hot sample as operator applies suction in a controlled manner with a hypodermic syringe, the air column in the tube controlling the amount of sample.



MANIPULATOR directs an oxyacetylene torch for remotely cutting steel plate.

of the various parts, at the desired varying speeds (photo, right).

Some designs permit the operator to combine motion of all parts of the manipulator arm by using directional motions. For example, to make the manipulator shoulder move in an upward northeasterly direction, he would make an up-east-north movement of a particular handle. This sort of combined motion requires skill, co-ordination, and thought and is actually useful only in traversing the motions of the manipulator's hand as it approaches the task.

The final position adjustments are then obtained by individual motions in sequence.

Rate-controlled manipulators range from light-duty models to those capable of exerting a force of 400 pounds in any direction.

Master-slave manipulators have the arm parts (photos, next page) driven through a control coupling from a master arm controlled by the operator. This master arm, designed to be grasped by the operator or strapped to his arm, follows the movements of the operator's arm and, through the control coupling, moves the slave arm. Forces met by the slave arm are transmitted back to the operator, giving him the feel necessary for his work.

No thought extraneous to the accomplishment of the operator's task has to enter his head—the main advantage of the master-slave manipulator (Box, page 52).

The control coupling of a master-slave manipulator can be either a mechanical coupling, such as a tape and pulley system, or a bilateral servomechanism.

A bilateral servomechanism maintains synchronism between the input and output of two similar mechanical elements, as wheels, while at the same time transmitting the forces applied or resisted by either to the other.

Servo units are in use with various types of power systems. Electric power and control are used most widely. When flammable vapor conditions are encountered, pneumatic and hydraulic units are desirable for safety. Controls for all these units are arranged compactly and conveniently for a push-button or lever type of operation outside the protection shields.

To date, master-slave manipulators are mostly mechanically coupled devices capable of handling weights of less than 10 pounds.

Remotely operated equipment requires safety features; for accidents with radioactive materials can spread contamination or cause loss of valuable materials and considerable time. Helpful safety features include limit switches for overload or overtravel, a sensing system for the tongs to avoid crushing or misplacement, a fail-safe arrangement, or an interlocking control system.

Special-purpose manipulators have been built for hundreds of purposes such as opening, filling, and capping bottles in the dispensing of radioisotopes or sample cutting and polishing for metallographic inspection. Their application by virtue of their one-purpose nature is mainly in repetitious operations or production processes.

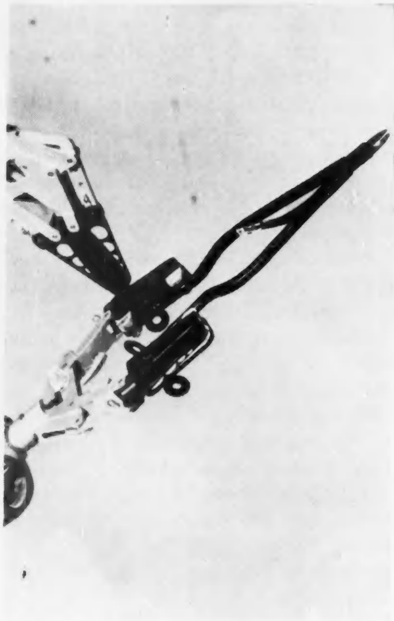
Generally speaking, economic considerations dictate the general choice of remote-handling equipment.

Laboratory Apparatus

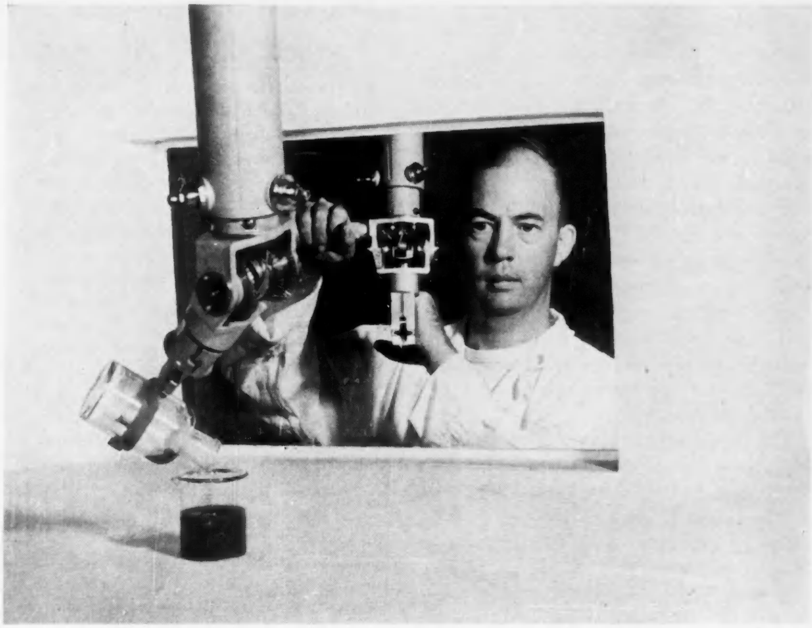
Radioactive materials complicate the functions of laboratory handling, making the use of special units essential.

Measurements, for instance, must be extremely accurate, for the quantities are small and the value great. Ordinarily, a sample is taken with a pipette by applying suction from the mouth; but in the radiochemical laboratories, the pipette is remotely used at the end of a supporting capillary tube (photo, left). Suction is applied in a controlled manner with hypodermic syringe or a piston moved with a fine-threaded screw, the air column in the tube controlling the amount of sample in the pipette. Several means of holding the pipette at the end of the tube permit changing without hand contact. The pipettes are often held firmly in a rack so that a friction grip can be used.

Again, a complete remote system can be arranged with motor drives for all motions. The pipetting equipment is



MASTER-SLAVE MANIPULATORS permit use of such tools as these light shears.



MECHANICAL HAND, through control coupling, follows movements of the operator's hands. Forces met by the slave arm are transmitted back, giving operator a feel for his work.

mounted on a dolly and track. A screw lift raises and lowers the tube, and a reversibly powered screw applies suction to take the sample.

Once a means for sampling is arranged, the transfer can be made from cask to filter, evaporator, heater, centrifuge, mixer, microscope, or other remotely operated equipment. This equipment can be located for a sequence of operation either in a straight line or in a circular path.

Many processes are arranged in closed systems, reducing handling to the simplest terms of operating switches, valves, and the like. All units are sealed carefully against escape of radioactive vapors, dusts, and liquids.

Many valves are operated with straight rods and universal joints or flexible shafting. Electric solenoid valves are often used. The valve that consists of a section of flexible plastics or rubber tubing collapsed by a motor-driven screw clamp at one point illustrates the variety of ingenuity required to produce leakproof, remotely operated, trouble-free controls.

Design of Handling Equipment

Necessity forces specialization in the field of handling equipment. Some of the design factors are singular to radioactive work, although many are of standard variety but applied with a higher degree of finesse. Various types of radiation are at a variety of energy levels and intensities, depending on the quantities to be handled. Handling of alpha, beta, and gamma types of emitters can be correlated with the safety shielding required for each. Quantities of material might range from milligrams to pounds, with radiation amounts from millicuries to hundreds of curies. This presents the problem of personnel exposure from several milliroentgens per hour to many roentgens per hour.

Weight or volume and size or shape of the container, as well as location of the material, must be considered. Will it be handled remotely over a barricade wall or through a passage in the wall or directly at a safe distance?

Materials of construction are chosen for strength, weight saving, durability, and corrosion resistance. To accurately and safely move delicate glassware containing critical liquids requires handling equipment of minimum weight. Because some liquids and gases are highly corrosive—even affecting stainless steel—suitable protection is required. Choice of bearings and bearing material must insure free and smooth operation with no suggestion of jerkiness or chatter. The feel at the handle of the unit should be as sensitive as if the hand were at the load.

Much standardization is possible in designing manipulators or tools, thus reducing cost—a large factor in this high-quality specialized equipment. The flexibility of equipment for a variety of uses is important for simplifying the installation, operation, and storage.

Although the various types of drives for transferring mechanical energy and motion from the hand to the grip that supports the load depend on the designer's philosophy, the need largely determines the method.

For close work—such as on alpha- and beta-emitting materials—a short, rigid connection is desirable. However, higher level beta and all gamma material require an extended length of control of more or less complicated design. For direct control, numerous combinations of the available flexible connections are possible, leading to the intriguing application problem of producing the most advantageous unit. Such possibilities could involve solid shafts and gears, concentric tubes for coinciding motions, flexible shafts for rotation and linear motion around corners; metal tape, small chain and cable for drives, and hydraulic systems on push-pull and gripping functions; and pneumatic systems for some work. For remote control where the hand receives little or no feel of the work, the application of electric drives and controls is highly successful.

If the choice has been special-purpose equipment, the problem resolves itself more into the realm of automation design than any other. Each operation to be performed is analyzed and a complete machine built for its accomplishment.

Because the operations can be programmed by mechanical, electric, or procedure means, the need for an operator is eliminated. The design problem of producing a piece of equipment to accomplish the task is usually straightforward, but the responsibility and reliability of the equipment designed are great. The whole remote-handling program usually hinges on each operating machine, much as a chain depends on its every link.

If the choice has been general-purpose manipulation equipment, the problems of design involve applying existing or new manipulators.

The application of existing designs, essentially the same as new manipulators, is mainly one of mounting the manipulators to get the desired working volumes with the most economic vision. Mountings on crane bridges, jib cranes, and fork trucks, with vision through windows, periscopes, water, and television have all been used in various combinations.

The problems of bilateral servomechanism design, coupling a human to a manipulator, and design of useful mechanical hands have been but lightly investigated when compared with a more normal industrial problem of steam-turbine or electric motor design.

Some of the ground rules for these problems are . . .

- The master station must not occupy any of the operator's space. It must accept or adjust to the wide variations in human stature. It must present a pleasant situation to the operator and not detract from his skill.
- The intermediate coupling should faithfully transmit its signals. It may be designed to aid the operator by either increasing his strength or his sensitivity. At the slave end, it must be resistant to radiation damage. Its safety features should prevent the operator from being maimed should the slave end meet with an accident.
- The slave station should duplicate the operation required to a degree that is acceptable to the operator. It should not occupy any unusual space that would limit some of the operator's skill. It should accept the normal tools of the trade of the particular operator—a chemist's beakers, pipettes, and dishes; a carpenter's hammer and saw; or a mechanic's wrenches and pliers.

Although complex and useful, manipulators are far from universal. They impose numerous restrictions on the designs of the devices they handle—a definite challenge to already burdened design engineers. Even standard items—screws, bolts, nuts, and connectors—receive careful attention as to accessibility and suitability for remote operation. Although at times special parts must be designed, commercially available parts can often be modified as alternatives.

Paralleling the designers' opportunities are those in the experimental and development fields. Once a nuclear reactor has been put into operation, there is no second chance to check out designs. Thus a design review committee should be established to review all designs from a remote-handling standpoint. If the feasibility of a particular design is questionable, the committee should recommend an experimental evaluation. Then, the development engineer is assigned the task of planning and conducting a test using laboratory remote-handling equipment and mock-ups of the particular proposed design. The rewards are threefold: it provides accurate information as to whether the design is satisfactory; any weak points are immediately apparent, and corrective modifications can easily be worked out; and a procedure for the remote maintenance or servicing of the design can be developed.

Special tools, jibs, fixtures, and equipment must also be considered. Whenever possible, standard tools are used in conjunction with the manipulators, but sometimes something extra is required. Many standard power tools—drills, nut runners, pneumatic hammers—can be easily modified for remote manipulation. A tremendous volume of challenging projects awaits the creative engineer in this new field—projects that must be taken from the initial study phase through development, design, and manufacture.

In every remote-handling facility, viewing presents a problem. The thick shielding walls contain windows (photo, right, page 51) made of such materials as lead glass and zinc bromide. Although these materials provide adequate protection, the manipulator operator gets a distorted or long-range view of his work. Periscopes and other such optical systems are also employed, but these systems usually lack the third dimension of depth.

Industrial television now appears to be a satisfactory solution. A camera focused on the work and a monitor at the control station give the operator an unobstructed view of his work. An additional TV camera focused in a plane perpendicular to the operator's line of sight or the stereo-television system could supply depth perception.

Combining the slave half of a servo-manipulator and a television camera into a highly mobile, versatile self-propelled machine will be a future step for remote-control design engineers. Control, via radio, would be from a console that contained the master arms of the manipulator, a television monitor, and all necessary transmitting and receiving equipment.

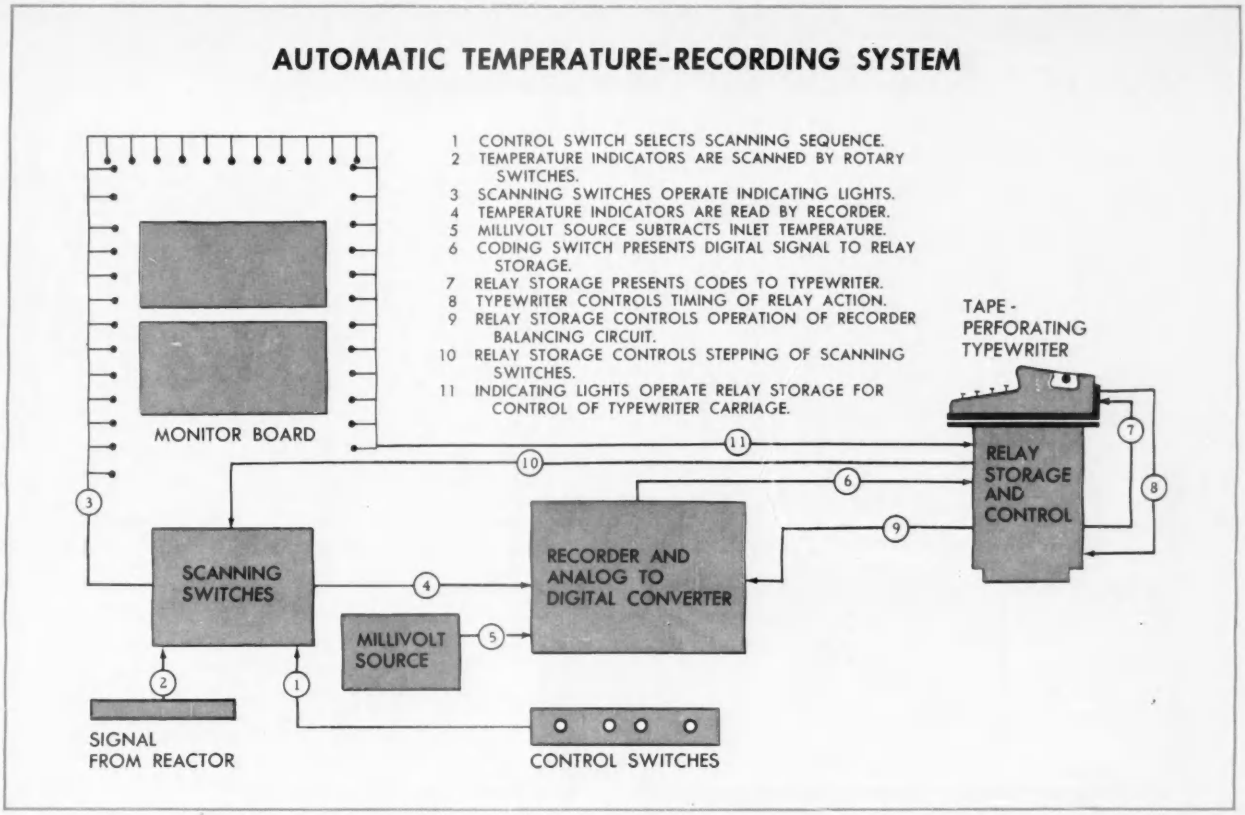
Various governmental and industrial radioactive laboratories are developing a wealth of knowledge and understanding in the handling of these new materials. Although the problems are not difficult and do not involve new and complicated theories, they do require the effective application of common mechanical systems to produce functional tools for a new philosophy. Ω

MANIPULATORS VS MAN

The master-slave manipulator can be compared biologically to the human being. For both have shoulder joints, arms, and wrists that in a manipulator terminate with a jaw. This mixed metaphor is becoming complicated because the manipulator's jaw now sometimes resembles a hand.

Just as a human technician can meet with an accident, so can a mechanical technician—the slave of a master-slave manipulator. Designed to transmit forces that it receives from its outside world back to the operator, it could conceivably pass back forces that might maim the operator. Therefore, devices have to be incorporated that limit the possible acceleration of the master arms and their extreme movements. These safety features must function if any accidental coupling occurs that would cause an oscillation between the systems of two motions—as elbow and wrist bend.

If the human operator were to become discouraged and angry trying to do a task with the manipulator, he could commit it to suicide by making the manipulator cut or disconnect its own power or control cables. However, the manipulator can be restored to life by repairing the break either manually or with another manipulator. Of course, such repairs could also be made on damages that are not self-induced. Three master-slave units would almost surely be self-maintaining, barring the most drastic accident.



AUTOMATIC TEMPERATURE RECORDER ELIMINATES THE EXPENSIVE DRUDGERY OF MANUAL DATA PROCESSING AT THE HANFORD OPERATION.

Data Processing in the Atomic Industry

By E. B. MONTGOMERY

The need for handling large masses of data from the Hanford nuclear reactors led to the development of automatic data-processing systems. And it is expected that similar systems of operation will be desirable throughout the atomic power industry. Because a close relationship exists between these systems and automation, knowledge of data handling will aid in a better understanding of the incentives for automatic data processing and automation in the atomic power industry. Let's examine some data-handling problems at Hanford that may be encountered elsewhere in this new industry.

In industry, automatic data processing includes the automatic performance of gathering data concerning the operation, reducing it to usable form, and comparing it with operating specifications.

Automation can be described as a system where the process, control, communication, and transporting of products function automatically; communication and control parts of the system are similar to the nervous system in animals.

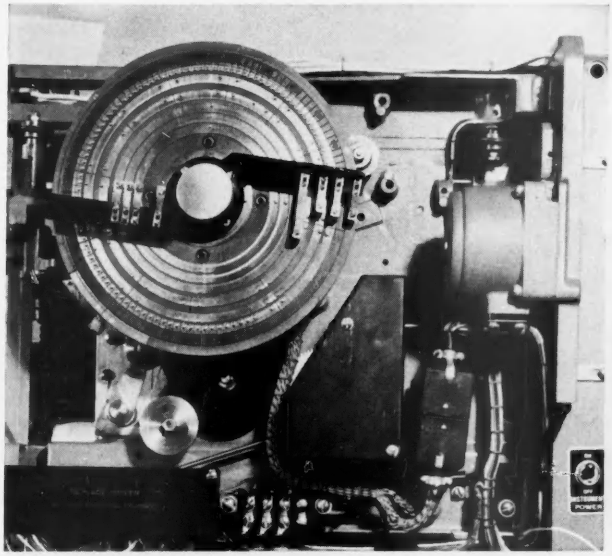
Recording Effluent Temperatures

From the beginning, the Hanford operation needed automatic data processing. Their nuclear reactors—the world's first production reactors—were equipped with hundreds of measuring and recording devices. Such instruments measured pressure, flow, temperature, power, ionization, nuclear particles, position, motion, and moisture, to name only a few. Data were measured in hundreds of places by several different techniques. The original method of handling the records of reactor-cooling-water effluent temperatures exemplifies the need for automatic data processing.

The Hanford nuclear reactors are pierced with hundreds of process tubes containing the aluminum-clad uranium fuel elements, or slugs. Water flowing past these slugs carries away the heat of the reaction. The temperature rise in the process water indicates the power in the tube. In addition, a plot of these temperature rises provides a two-dimensional map of the distribution of power in the reactor.

As stepping switches successively connect the thermometers to the recorder circuit, the temperatures measured in the reactor are recorded one by

Associated with reactor physics experiments and data processing during his 11 years with GE, Mr. Montgomery is presently Specialist—Data Processing, Advance Engineering Section, Hanford.



ANALOG-TO-DIGITAL converters in addition to the associated relay-network system activate the proper key-punch machine.

RELAY-STORAGE and control unit directs digitized information from converter to tape-perforating typewriter—a vital function.

one—a process costing little human effort. However, further manipulation of the hundreds of data points becomes expensive if manual effort is necessary. If temperature profiles are needed at frequent intervals, the cost of manual processing is prohibitive.

Although predictable, the behavior of large-scale reactors did not allow the usual margins of calculated risk. Limited experience with nuclear reactors indicated a need for considerable research. By using the myriad data produced, analytical predictions could be correlated with operating experience. But most of these important calculations were performed manually. Originally, plant equipment included the standard commercial punch-card machines. However, before the data could be assimilated by these machines, at least two manual operations were necessary: reading charts and punching cards.

Finding a Better Way

The expensive drudgery of such manual processing led to the desire for a better way—a system lacking the endless arithmetic and hand copying.

Once arrived at, the answer was relatively simple. The same devices that recorded data on strip charts could be made to punch cards for machine handling. Thus card-punch machines could become a part of the standard equipment of each operating reactor.

The development of analog-to-digital converters as well as the associated relay network needed to activate the appropriate key-punch machine was straightforward. The analog-to-digital conversion translated the angular position of the strip-chart-recorder drive motor to digital information acceptable to the card-punch machine.

So far, the system was a good one. Placing a stack of cards in a machine, flipping a few switches, and waiting for the accurately punched deck seemed a simple matter. But one factor had been overlooked—the machine operator's skill. The practiced operator handles a deck of cards with apparent carelessness, yet puts them through the machine without causing trouble. The reactor operators handled these decks so infrequently that they could not maintain trouble-free operation.

Again, a search for a better way began. The automatically operated typewriter designed for office use offered a solution by providing a perforated tape. This tape would remove the handling difficulties encountered with decks of cards. Vendors of such typewriters agreed to adapt a machine to such use, permitting the strip-chart recorder to function while perforating a tape and typing a table of readings. This solved the problem.

During this time, a card-programmed computer supplemented the research and development programs at Hanford. With the addition of a tape-to-punch-card converter, improved computing facilities allowed the use of production data for research. In addition, the perforated tapes could be used for more complex production control and scheduling. All this provided for mass production of research data on operating reactors.

Exploiting the potential of this data-processing system has just begun. Extensions of automatic data-processing concepts are evolving that allow much greater precision in engineering research and more efficient production. Ultimately, such a system will provide . . .

- Necessary data required for effective automation
- A satisfactory communication system for the automation system
- Mass production of necessary research data
- Better production control and scheduling.

A Fully Automatic Reactor

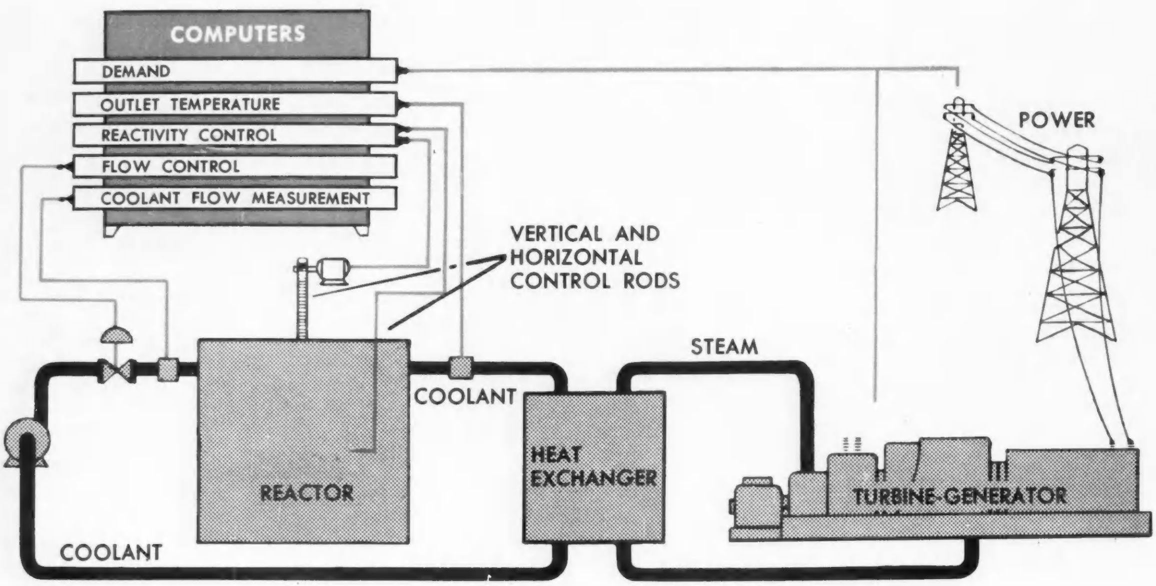
Let's speculate on the future development of a fully automatic reactor. Computation of all operating transients will be performed by analog or digital devices, taking their information directly from stored data.

The concept of a production reactor, with its fuel preparation and separation of irradiation by-products, portrays automation potential to its fullest development. Automation may be separated into three technologies, all applicable to the atomic energy field.

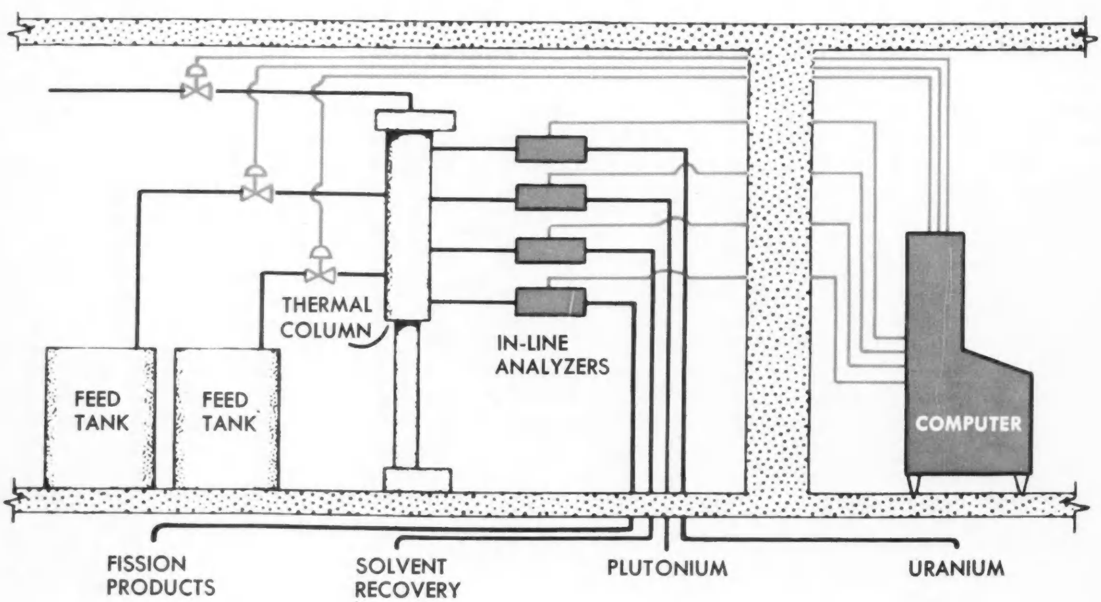
First, fuel preparation for all but homogeneous reactors will require the automation concepts of the automatic factory, producing manufactured pieces that might be quite complex and that

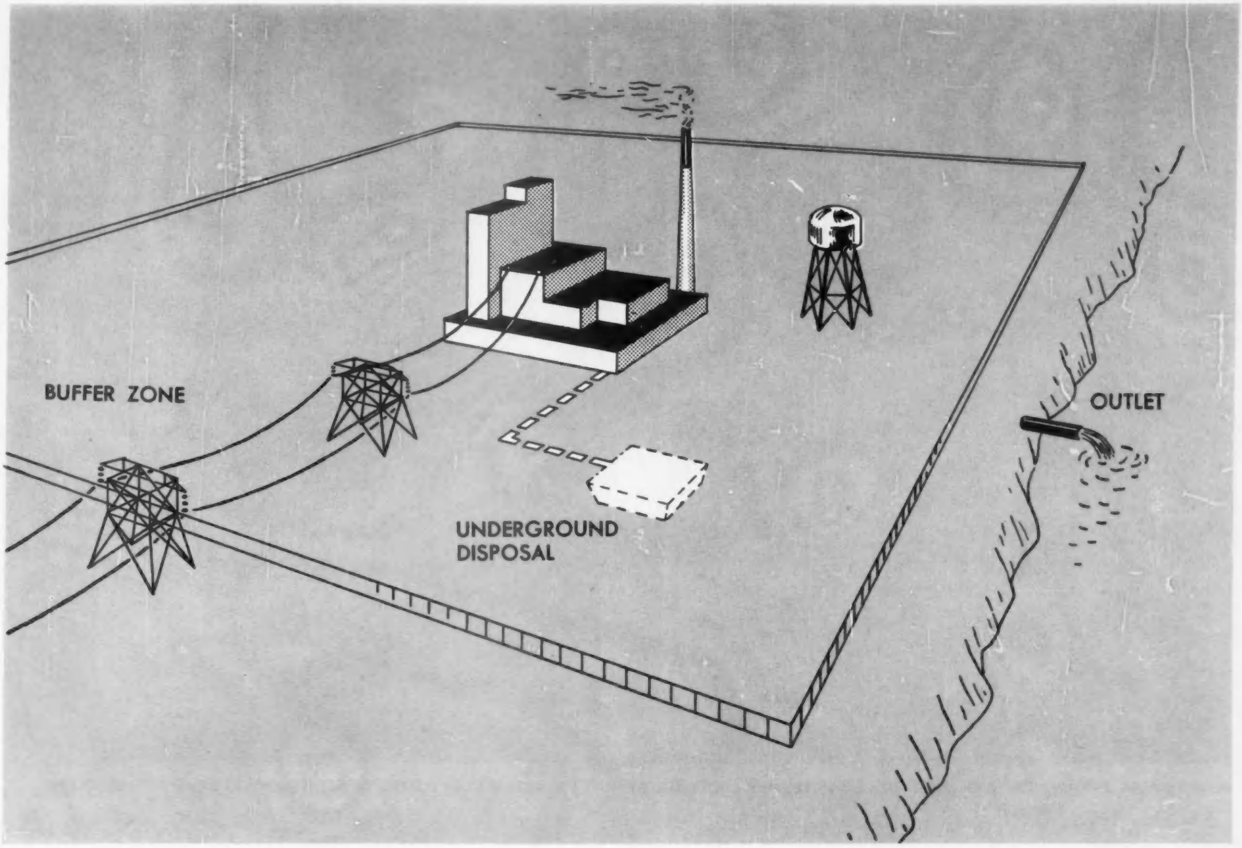
NEW HORIZONS FOR AUTOMATION . . .

Power Reactors



Product Separation





SAFETY PRECAUTIONS WILL INSURE THE PROTECTION OF INDUSTRIAL AND RESIDENTIAL AREAS FROM AIR AND WATER CONTAMINATION.

Overcoming Radiation Hazards of Atomic Power Plants

By J. F. HONSTEAD

Whenever technological developments are moved from the scientist's laboratory notebooks to full-scale industrial application, engineers are faced with new safety problems and new operational hazards. From its origin as a mere laboratory curiosity, the development of electricity to furnish lights for cities and power for factories required the development of appropriate safety practices.

And now, the harnessing of atomic energy demands its own set of safety practices. Just as engineers of earlier days were concerned with the safe application of a new and frightening form of energy, the engineers of today must also provide protection against the radiation hazards associated with nuclear power.

Safety in Designing the Plant . . .

While many of the design problems faced in building an atomic power plant are similar to those encountered in a conventional steam plant, others deal with a new hazard—radiation. This hazard often appears exaggerated because of the unfamiliar, intangible quality of the problem.

You can add several new terms to your vocabulary, including some new units of measurement encountered. When studying the problem of radiation safety, dosage rate refers to the rate that the energy of ionizing radiation is imparted to matter, frequently emitted from nearby radioactive material. For mixtures of beta and gamma radiation, the dosage rate is commonly expressed in units of rads per hour. The rad—a basic unit of absorbed dosage of radiation—is a quantity of any type of radiation releasing through ionization 100 ergs per gram of irradiated matter. However, this quantity is rather large compared with the amount that a person would be exposed to in a day, and so the term is usually expressed in one thousandth of a rad, or a millirad. Contamination refers to radioactive material existing in any place where it is not desired, particularly in any place where its presence may be harmful. For example, radioactive material found clinging to work surfaces, floors, or tools is usually regarded as contamination and commonly expressed in units of microcuries per unit of area or volume.

Experience shows that atomic reactors can be operated safely and employees

WHY APPLY AUTOMATION TO THE ATOMIC POWER INDUSTRY?

REMODELING IMPRACTICAL—With the atomic power industry so new, it will be easier to design from an automation philosophy than to renovate existing plants.

REMOTE CONTROLS ADAPTABLE—Throughout the atomic power field, the necessity for shielding has forced the development of remote controls. The cost of this expensive part of automation will therefore be shared by functions other than automation.

MATERIALS EFFICIENTLY UTILIZED—Reactor construction cost is high because of the added cost of shielding, remote control, and design for minimum maintenance. In addition, the fissionable materials are very valuable. With capital and inventory costs of this magnitude, the pressure for efficient utilization will be high.

MAINTENANCE COSTS REDUCED—Automation can assist in cutting maintenance costs by insuring close adherence to operating criteria agreed upon as lowering needs for maintenance.

RESEARCH DATA TRANSLATED—Much data for nuclear energy research comes from observing the behavior of operating plants. Automatic data-processing equipment greatly facilitates translating such information for research studies.

SUCCESS IN COMPARABLE INDUSTRIES—The present high level of automation in the utilities business will probably insure that automation in the atomic power field is at least comparable with that in conventional utility installations.

SAFETY ASSURANCE—Safety requirements in atomic power will be stringent. Well-designed automatic controls are safer than human operators because mechanical brains can think of nothing but their designed duty.

PERSONNEL SHORTAGE—A high ratio of technical-to-nontechnical personnel will continue. This shortage of technically trained men will add pressure to the need for automation.

PRELIMINARY GROUNDWORK—Normally, the cost of applying automation depends on a considerable outlay for research and development. However, in the atomic power field most of this work is already being carried out.

demand high standards of fabrication. In such a factory, fuel-element production will be typified by automatic transport between the many stages of automatic assembly or fabrication, by rigid control of each part of the process with automatic gaging and inspection, and by rejection of substandard components. Digital computers that count, rather than analog devices that measure, will probably predominate among the control equipment for plants producing discrete pieces of fuel. Small special-purpose computers would control most of the fabricating units. Such controls would allow direct accounting of the valuable process materials used by such a plant.

Whether for production of power, new isotopes, or new fuels, the reactors themselves will probably fit a second type of controlling and automation concept. The safe control of reactors, particularly those with extremely short reaction times, will demand the utmost in fail-safe design philosophy. For example, without the aid of anticipator-type controls that can operate at the speed of electronic devices, human operators could not control fast reactors—those lacking a moderator to slow down the neutrons. Automation of this type typifies the popular picture of the giant brain. Actually, however, the giant brain as such does not exist. The large, tremendously fast computers perform high-speed repetitious operations of the simplest type. But without human programmers to plan beforehand in extreme detail, computers could not function.

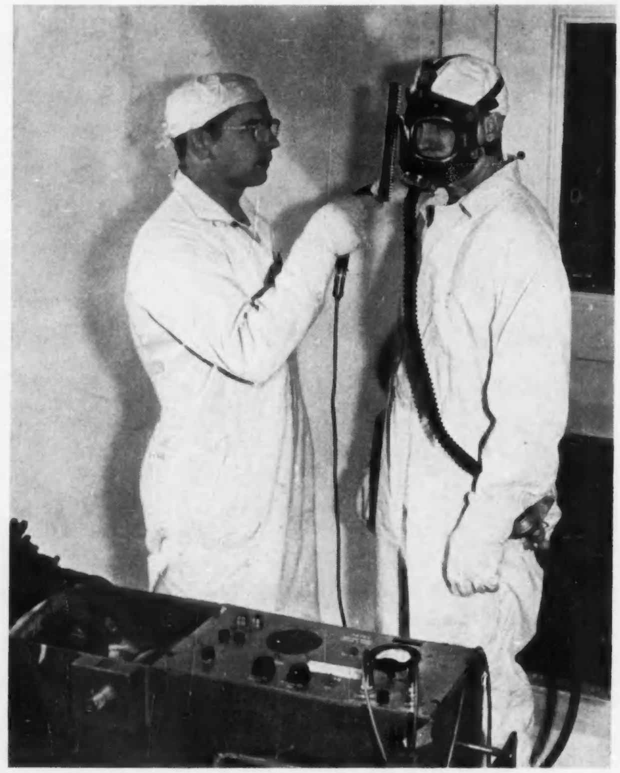
The giant brain is not a new idea nor is the refutation of this idea new. In the early 19th century, the analytical engine of England's Charles Babbage elicited this comment from Lady Lovelace, the daughter of the poet Byron: "The analytical engine has no pretensions whatever to originate anything. It can do whatever we order it to perform." This statement is just as true today.

The third type of automation—the automatic continuous-flow process plant—will probably be found in the separation processes. Today, most automatic controls are designed to fit the needs of such chemical process plants.

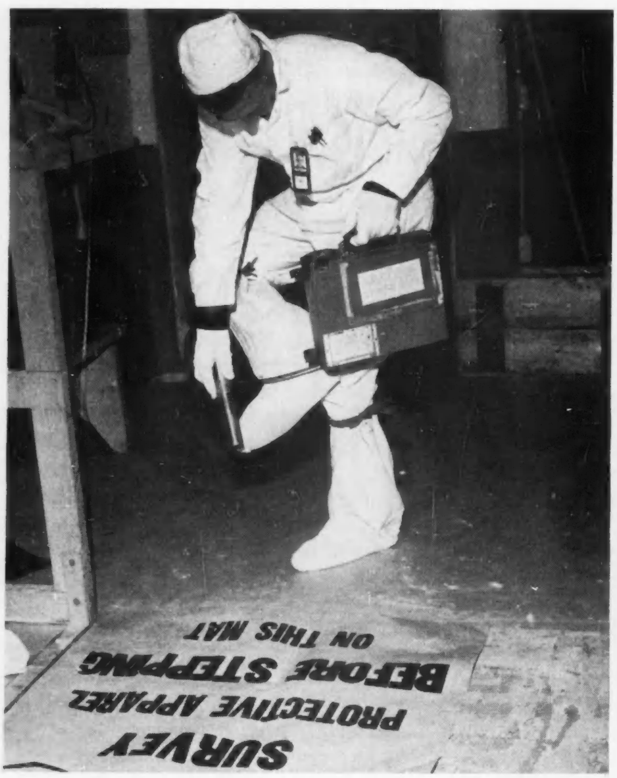
Although chemical plants lend themselves to automatic control, few, if any, are completely automatic. Principally, they lack automatic in-line chemical-analysis techniques and equipment, with most of the other components of an automatic process plant available. By thinking of the chemical plant as a continuous process, you'll see how easily automation functions. With appropriate automatic chemical analysis at the sensitive points in the process, specially designed computers can take the results of the chemical analyses and compare them with product specifications. Then the computer feeds back changes to the input side of the reaction from which the output was sampled for the automatic analysis.

Expectations

Many reasons exist for the development of high-level automation in the atomic power industry of the future (Box). And automatic data processing will play an important role in automation's progress by providing the necessary data, a communication system, and mass production of the research data essential to the functioning of the proper system. Being limited only by economic considerations, future expectations promise advances in engineering research plus more efficient production.Ω



MONITORING PERSONNEL, WHO MUST WEAR PROTECTIVE CLOTHING AND OFTEN RESPIRATORY EQUIPMENT, GUARD ATOMIC POWER PLANTS . . .

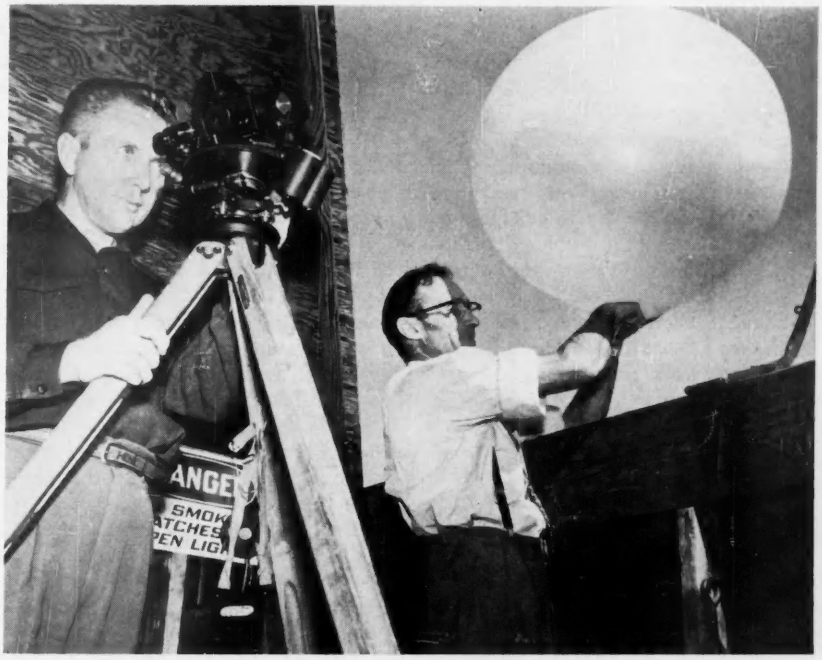


. . . POLICING THE INTERIOR AND THE SURROUNDING AREA TO DETERMINE AND CONTROL THE LEVELS AND ZONES OF CONTAMINATION.

protected from harmful amounts of radiation. To accomplish this, however, special rules of conduct for employees must be enforced. Plans for shielding and isolating various areas must be incorporated into the basic plant design. The plant organization also needs a special personnel group to monitor and devise adequate radiation safety procedures.

Undoubtedly, certain areas in the plant will have to be restricted to short personnel work time because of high dosage rates. If frequent maintenance work is required within those areas, additional manpower may be required to limit the time spent by each man in these high-level zones. Careful design of the plant with respect to the relative position of the various components permits locating those pumps, motors, and valves that need frequent attention in areas of low radiation intensity. This reduces the operating force required.

Regardless of the type of reactor chosen as a source of power, the plant will generate a certain amount of radioactive waste material. Some method of handling and disposing of this waste must be a part of the over-all design. The safe disposal of radioactive wastes may be an important economic factor in evaluating the type of reactor selected. Allowance must also be made in the disposal system for an unexpected release of material as a consequence of equipment failure.



WIND PATTERNS AND OTHER METEOROLOGICAL DATA AID IN PROPER PLANT-SITE SELECTION.

. . . and in Choosing a Site

Even though the reactor will be equipped with many safety devices, the consequences of a possible incident must be evaluated and steps taken to restrict the damage that could result. Such an evaluation will probably affect the choice of location for the plant as well as the size of the site needed for it. In general, an incident would consist of a power surge that would rupture the reactor and possibly vaporize part of the fuel, releasing highly radioactive fission products. Minimizing the effect on the surrounding area of such a large-scale release of material is an important consideration in selecting a suitable site.

The industrial and residential areas adjacent to a plant can be safeguarded in two ways. The plant may be surrounded with a wide buffer zone to reduce the effect of such an occurrence on neighbors or encased in a large sealed tank strong enough to contain the vaporized products of a possible incident.

Because marketing considerations may dictate that the power plant be located within a highly industrialized region having high real-estate values, a buffer zone could represent a major investment—making it more economical to build a structure to retain the fission products. A current application of this containment principle is found in the large steel sphere now housing a land-based prototype of the Submarine Intermediate Reactor, West Milton, NY.

Other considerations that will affect the selection of a plant location include those of air- and water-pollution control resulting from the disposal of radioactive wastes. Ventilation air from the plant must be discharged to a tall stack. The prevailing wind direction and frequency of atmospheric-temperature inversions must be studied to evaluate the hazard of any radioactive material to the surrounding area. The plant should be so located that the average direction of the wind is away from nearby residential or industrial areas.

If the plant depends on dilution and dispersion of liquid wastes for disposal, an adequate fresh water supply must be nearby. The proximity of neighboring installations using the water source for sanitary or industrial supplies will also be a factor.

Safeguarding Operating Personnel . . .

By utilizing shielding and isolation where possible and controlling exposure time in radiation zones, operating personnel can be protected from excessive radiation dosages. Besides the massive biological and thermal shield required around the reactor itself, a shield is also required for the components of the primary circulation loop of the power plant. The primary loop contains the coolant that circulates continuously through the reactor and an adjacent heat exchanger or boiler. Some of the coolant and corrosion products or other impurities it contains become radioactive during passage through the reactor. Clinging of this material to wetted surfaces of the primary loop will result in high dosage rates in the vicinity, representing a potential operational problem. The materials that form the loop are important, for a proper choice can keep corrosion low and also avoid the occurrence of those isotopes that are easily activated in the reactor or that have long half-lives after irradiation. Ease of adsorption of these radioactive materials on the exposed surfaces of the loop must also be investigated.

The concentration of irradiated impurities in the primary loop coolant can be reduced by passing through ion exchange beds or by continuously bleeding off a small stream and replacing it with clean coolant. Ion exchange beds already in the primary loop may be utilized for this purpose. The coolant purification process is a source of radioactive waste that disposal must be planned for.

Protecting personnel from the hazards associated with contamination within the plant requires constant vigilance. Contaminated areas should be posted and steps taken to decontaminate them. Protective clothing and respiratory protection should be provided for men working in areas of probable contamination. In addition, some form of personal monitoring for each man and his equipment should be required before he leaves a contaminated area. Because human senses cannot detect the presence of radiation, trained monitoring personnel must accompany workmen into contaminated areas or radiation zones to establish dosage rates with monitoring instruments and set time limits. A system of measuring and recording the dose each man receives should be established by providing them with personnel meters—such as film badges or pocket ion chambers.

Radioactive material is a serious hazard if permitted to enter the human body by absorption through the skin, inhalation into the lungs, or passage into the digestive system. The safety measures required to keep the amount of radioactive material assimilated by plant personnel within safe limits are similar to those used by any industry handling toxic chemicals. The main difference in their protective requirements stems from the much smaller concentrations of radioactive material that can be safely ingested. Frequent air and water sampling, plus rigid regulations regarding the use of protective clothing and eating or smoking in contaminated areas, helps to reduce the danger. The probability of air-borne contamination should be considered when specifying the air-conditioning requirements of the plant. Air flow through the plant should generally be from areas where little or no contamination is anticipated toward areas more likely to be contaminated.

. . . and Area Neighbors

Adequate precautions will prevent the areas adjacent to the power plant from being subjected to air-borne contamination from the plant's stack and their water supplies from becoming contaminated with plant waste. Safeguarding area neighbors is the responsibility of the operator of an atomic power plant.

Two general methods are available for the handling of radioactive liquid wastes: concentration and containment, and dispersal and dilution. The containment principle involves storing the wastes in large tanks or vaults for long enough periods for the radioactive material to decay until it reaches a safe concentration. If the waste contains a large amount of long-lived material, lengthy storage may be required. Because this is not economically feasible for large volumes of waste, the storage charges may be reduced by concentrating the wastes and reducing their volume. The resulting high-concentration low-volume waste solution can then be stored at the plant site or transported to storage facilities in a more remote locality. Or, waste concentration might be accomplished by direct evaporation or by adsorption of the radioactive material on the ion exchange surfaces of natural clay or synthetic resins. Such waste can sometimes be sealed in metal containers or mixed with concrete for underground burial or ocean disposal.

The principle of dispersal as a safe method of disposing of radioactive wastes is essentially applicable to large volumes of low-concentration wastes, particularly those containing primarily short-lived isotopes. Radioactive gaseous waste and other air-borne waste material are generally disposed of by this method. When plants discharge large amounts of radioactive particulate matter as dust in the air stream, filters for the stack effluent must be provided. Sometimes, liquid wastes containing short-lived isotopes are dispersed into large rivers or into the ocean. The use of pits or underground cribs to dispose of liquid wastes may be an economically attractive solution to this problem. Existing beds of natural clay can be used to advantage for retention of waste material by ion exchange as the waste percolates through them. However, adsorption and decay must reduce the concentration of the wastes to a safe level before underground drainage delivers the material into the public domain. Thus a detailed geological and hydrological survey of the disposal site should precede such a disposal plan to ensure this.

Fission products in the fuel assemblies of atomic power plants are also subject to long-range disposal practices. Regardless of the type of reactor used or the design of its fuel assemblies, the problem of disposing of these products must be faced. Of the isotopes formed during fisson, a potential hazard in drinking-water supplies is created by the long-lived strontium-90 (Sr-90) present. This isotope has a half-life of about 20 years and a recommended maximum safe concentration in drinking water of 8×10^{-7} microcuries per cubic centimeter. In addition, Sr-90 represents a significant fraction of the isotopes formed during fission. To grasp the significance of the amount of Sr-90 formed in a power reactor, let's assume that a plant has a production capacity of 300 megawatts of electric power using U-235 for fuel. After eight years of continuous operation, the reactor would create enough Sr-90 to raise all the water in Lake Michigan to the maximum safe concentration for drinking purposes. If the fission products were regularly removed from the fuel assemblies of such a reactor and continuously bled into a river as large as the Mississippi at its mouth, the river water would be contaminated by Sr-90 to more than twice the safe concentration for drinking. From this example, it is clear that disposal of high-concentration waste fission products, unlike disposal of low-concentration liquid wastes containing short-lived isotopes, cannot be accomplished by dilution in natural surface water. The safe operation of large atomic power plants requires other methods of disposing of these waste fission products. Their ultimate disposal in a safe, economically sound manner is a challenge that will be surmounted by the ingenuity of engineers developing industrial atomic power.

Future Safety—A Routine Matter

Atomic power plants will be operated safely because proper consideration will be given to radiation and contamination problems while designing the plant and establishing its operating procedures. Plans for treating and disposing of wastes will be considered early in the design stages of the plant. An adequate radiation protection program for the safety of the operating and maintenance personnel will be carried out. Just as the use of insulation has become a routine safeguard against electric hazards, radiation protection will also become a routine matter in the atomic power plants of the future. Ω

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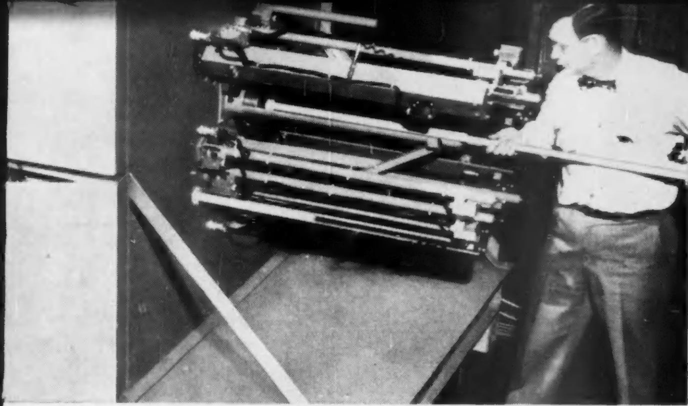
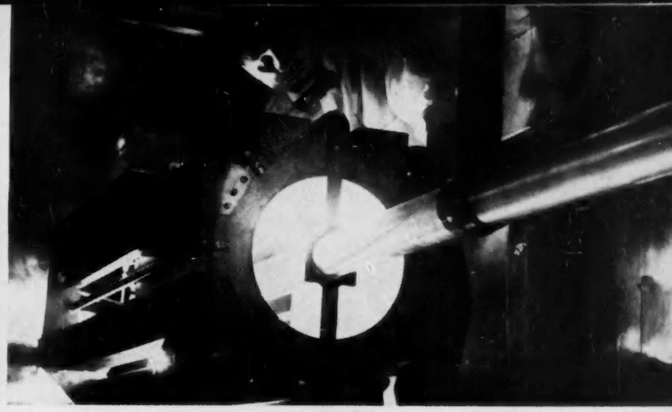
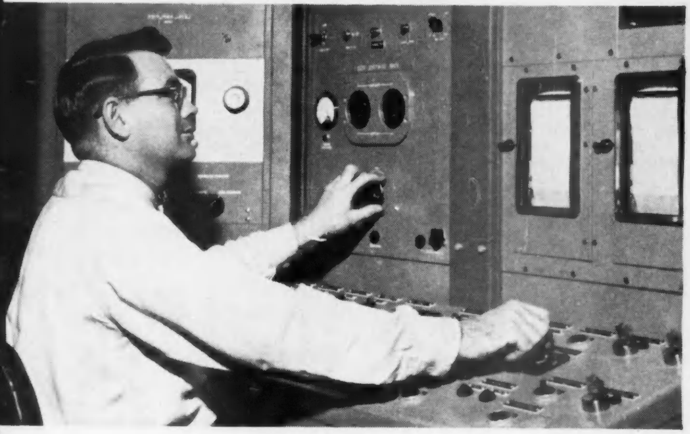
Mr. Honstead joined General Electric in 1950 in the Biophysics Section of the Radiological Sciences Department at Hanford. Presently, he is an engineer in the Radiological Engineering Section, Radiological Sciences Department, Hanford.



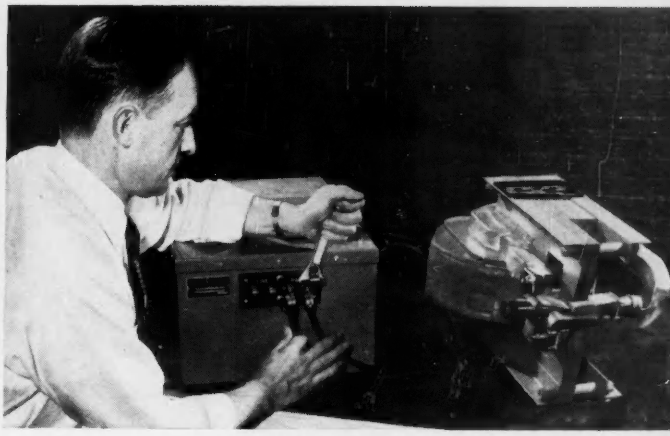
Reactor Control Rods



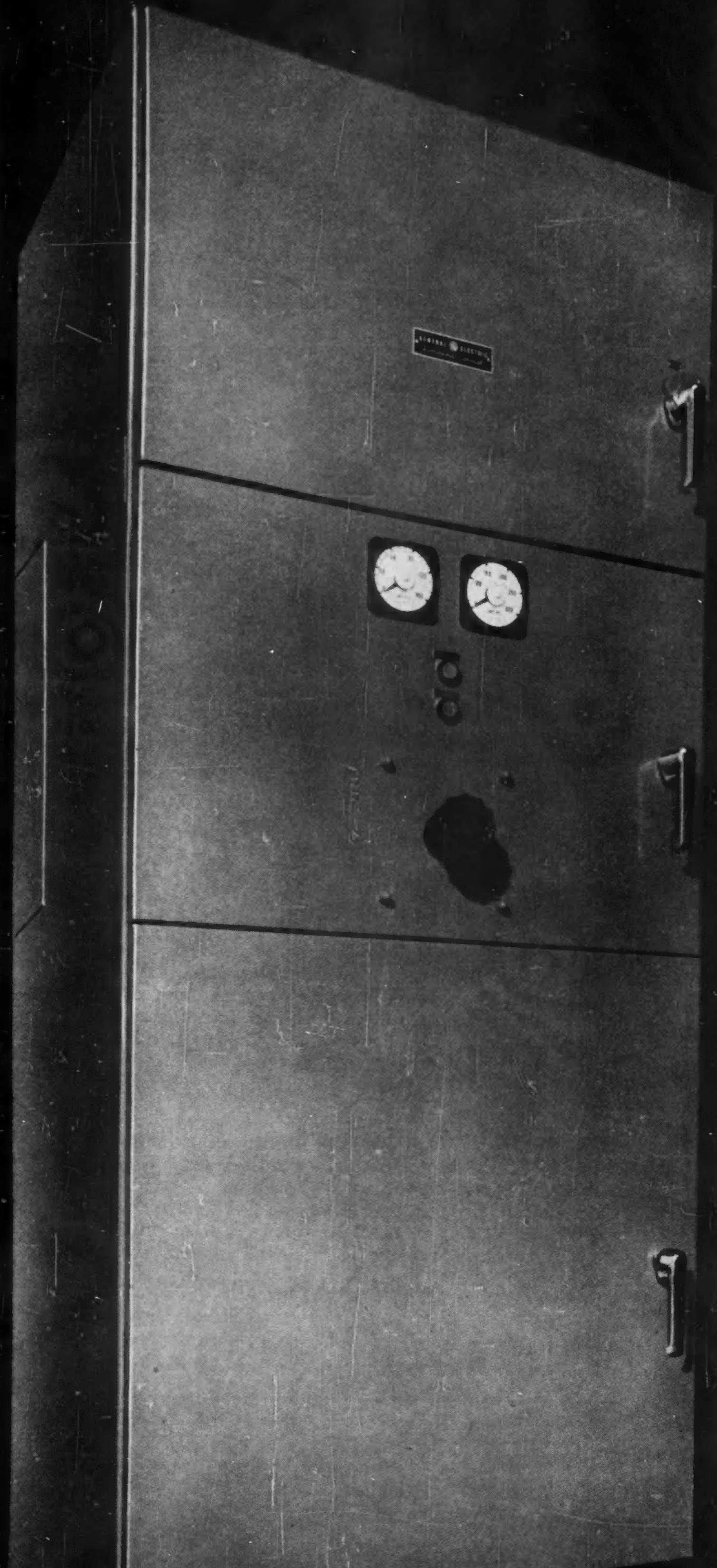
Reactor Core

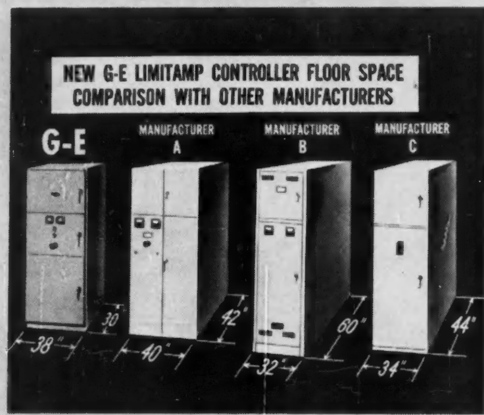


Control Console for Reactor System



Electromagnetic Pump





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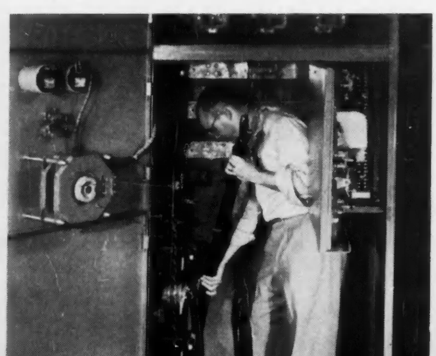

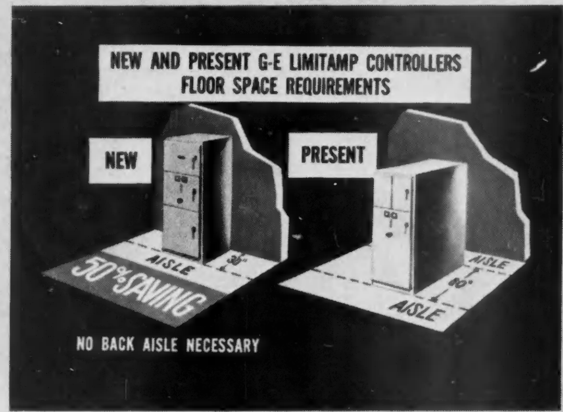

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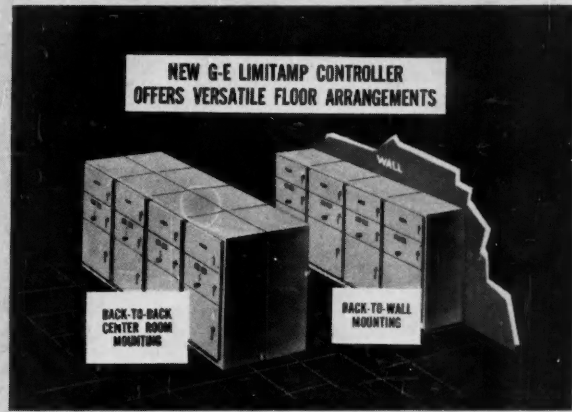

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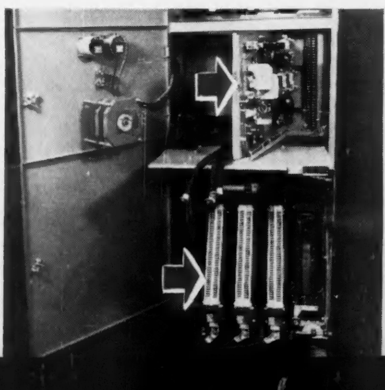
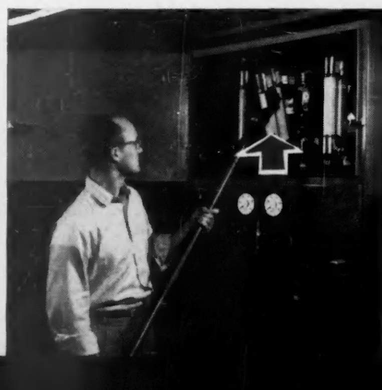
MAINTENANCE IS EASY. Low-voltage panel swings out, contactor rolls out.



TYPE EJ-2 CURRENT-LIMITING fuses are safely, quickly replaced within seconds.



SAFE VISUAL CHECK of disconnect switch with fuse compartment door open.