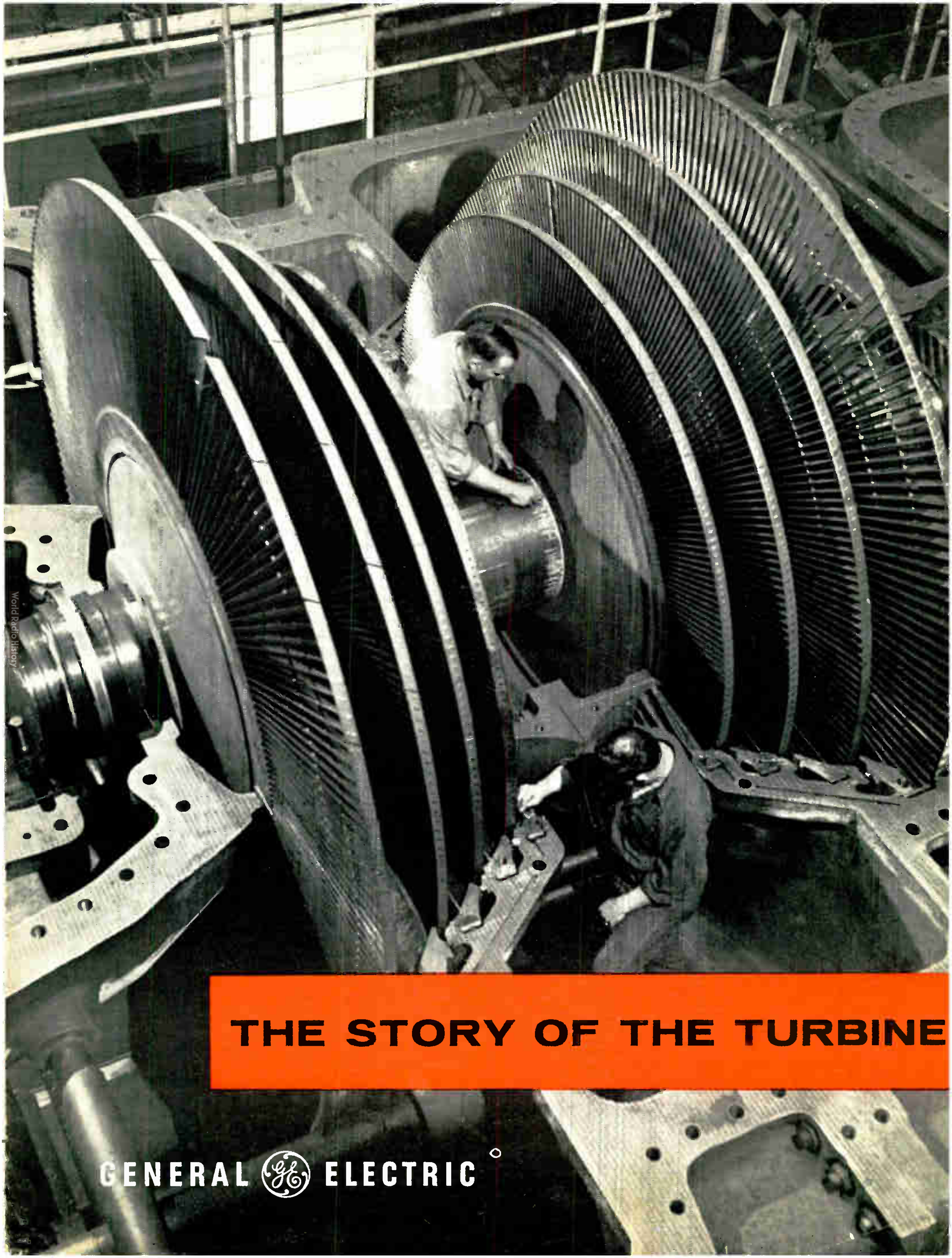
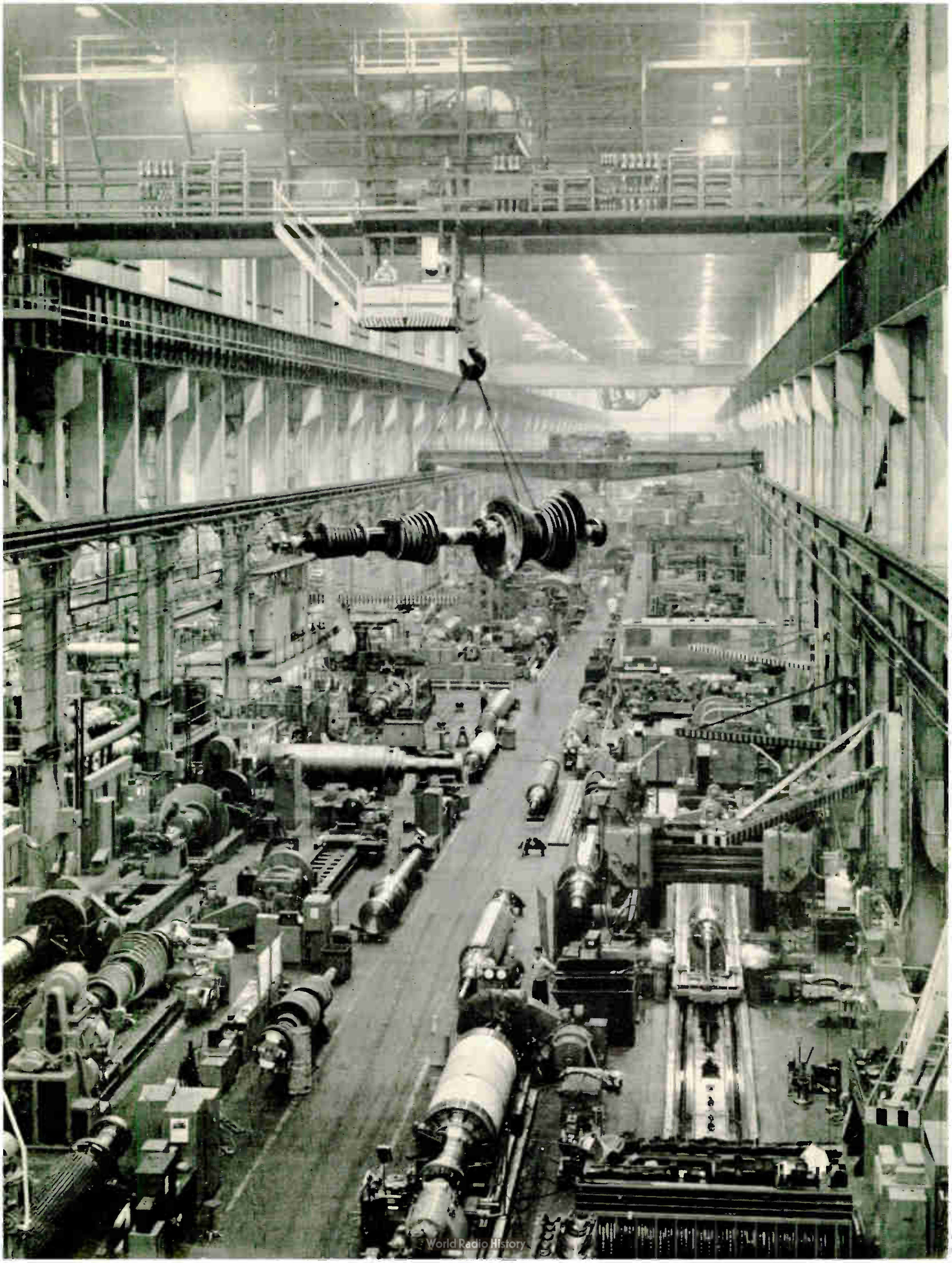
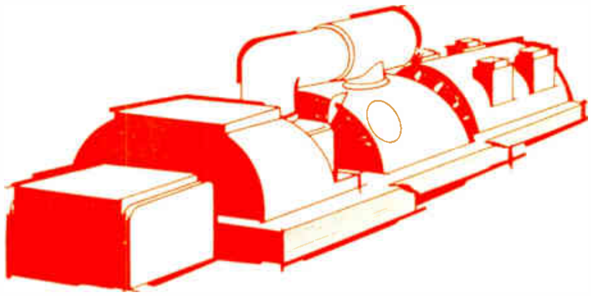


THE STORY OF THE TURBINE

GENERAL ELECTRIC



the story of the turbine



A machine we seldom see performs everyday miracles to provide the power we live by

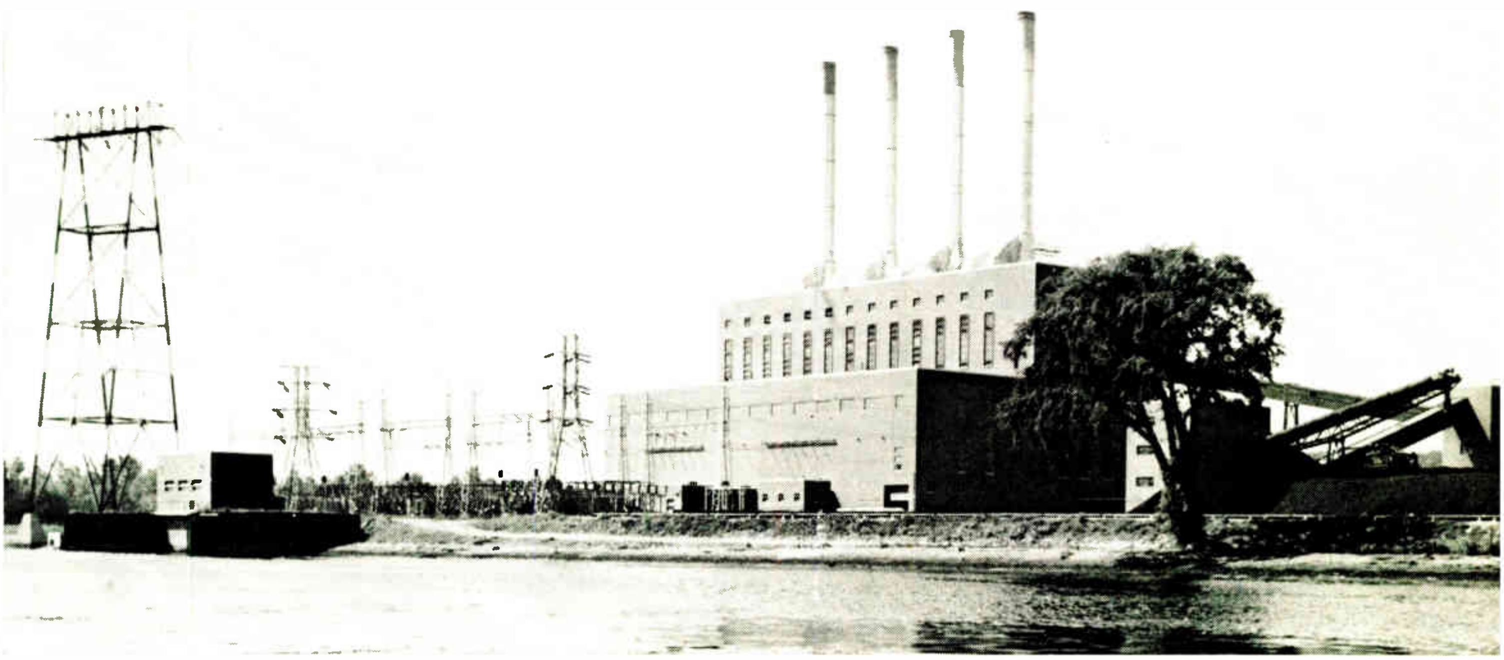
When Edison invented the incandescent electric light in 1879, he contributed the first of the three essential elements for today's tremendous electric power business. Three years later, when he built the world's first system of distributing electric power to numerous individual users from a single centrally located generating station, he contributed the second essential. The third, the turbine-generator, was not developed in practical form in the United States until 1901.

Edison's incandescent lamp, though not the first electric light, was the first of conveniently small size, and the first that could be turned on and off at will. The central station power system which he devised was like a town water supply system to take the place of individual wells in the back yards of houses. His dynamo, or generator, was a fairly efficient machine, but he had to drive it by means of a steam piston-engine and an arrangement of belts and pulleys which were noisy and cumbersome.

We Live by Electricity

In the 80-odd years since these early developments, electric power has become one of the cornerstones of our civilization. Today the United States uses nearly 800 billion kilowatt-hours of electricity every year. In terms of manpower, this is equal to a year's work of 12 billion men, more than triple the world's population.

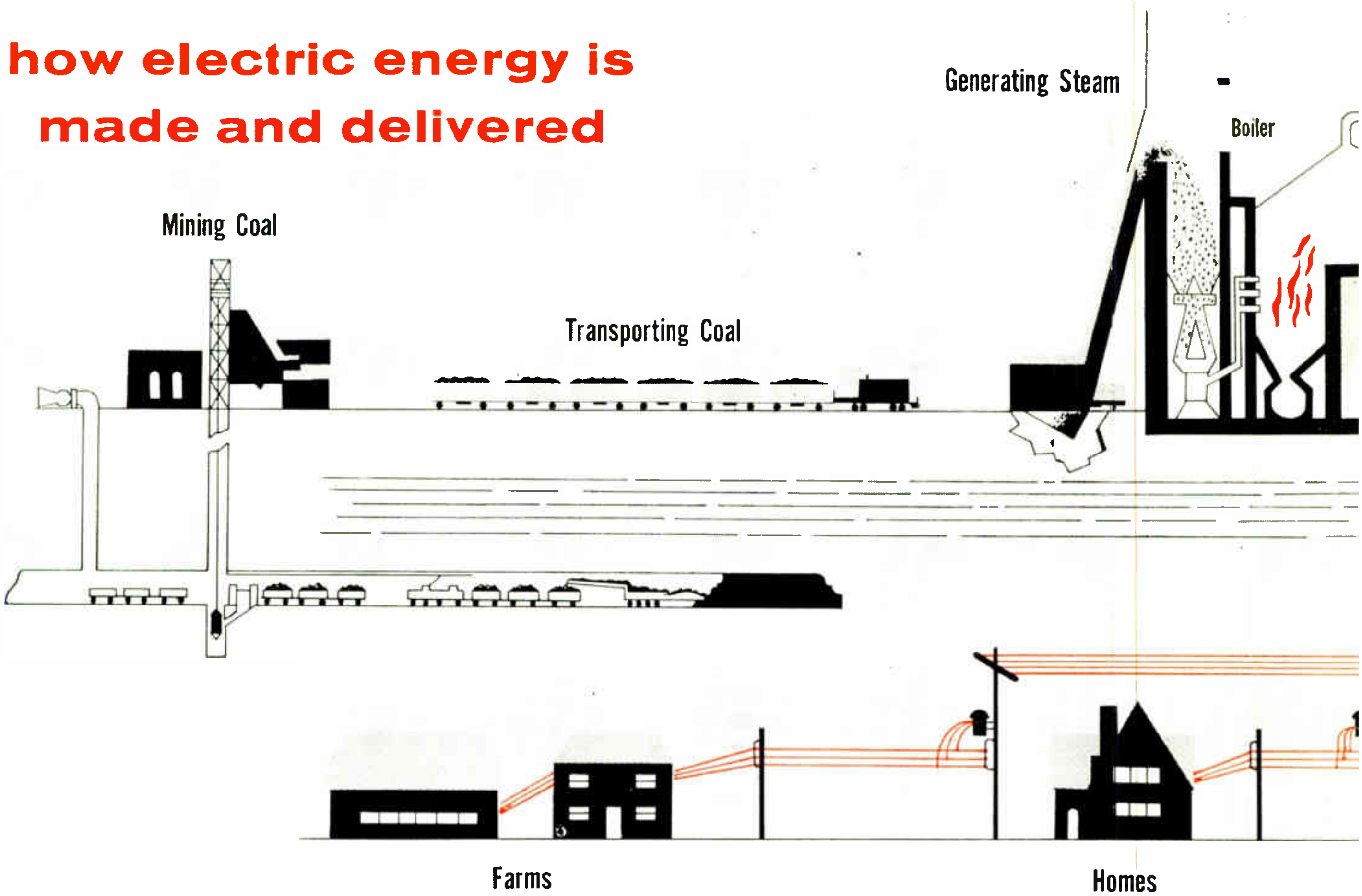
We wake in the morning to the sound of an electric alarm clock and radio. We work and dress by electric light. Our breakfast toast and coffee are prepared electrically. The butter and cream we use are kept fresh and sweet in an electric refrig-



This is what you see from the fourth-floor balcony of the mammoth, modern building where General Electric builds its large steam turbine-generators, at Schenectady, New York.

Today's electric power-generating station meets the increasing demands for electricity and in the face of mounting operational costs keeps the cost of the kw-hr at a low level.

how electric energy is made and delivered



erator. After breakfast, the dishes are washed in an electric dishwasher, and perhaps the tablecloth and napkin we use are washed in an electric washer and pressed by an electric iron. Crumbs are removed from the floor by an electric vacuum cleaner. Altogether some 600 million home appliances are in use in the United States. The typical house has more than a dozen of them. Many houses are also heated by electricity.

In business and industry, the use of electricity is a part of almost every activity. It lights the buildings and runs the elevators. It provides essential transportation services in large cities; it turns the wheels in factories. It is the basis of many industrial processes, such as the production of aluminum. It controls the operation of complex machines with speed and precision. In the form of computers, it takes the place of much human brainwork.

Electricity has revolutionized agriculture throughout the country. Whether in the narrow valleys of New England or on the great plains of the Midwest, more than ninety-five percent of all farms are supplied with electricity. It grinds the corn, cures the hay, milks the cows, churns the butter, and performs dozens of other useful tasks that once were done slowly and laboriously by hand. At the same time, it has brought to the farm many of the conveniences that were previously enjoyed only by city dwellers.

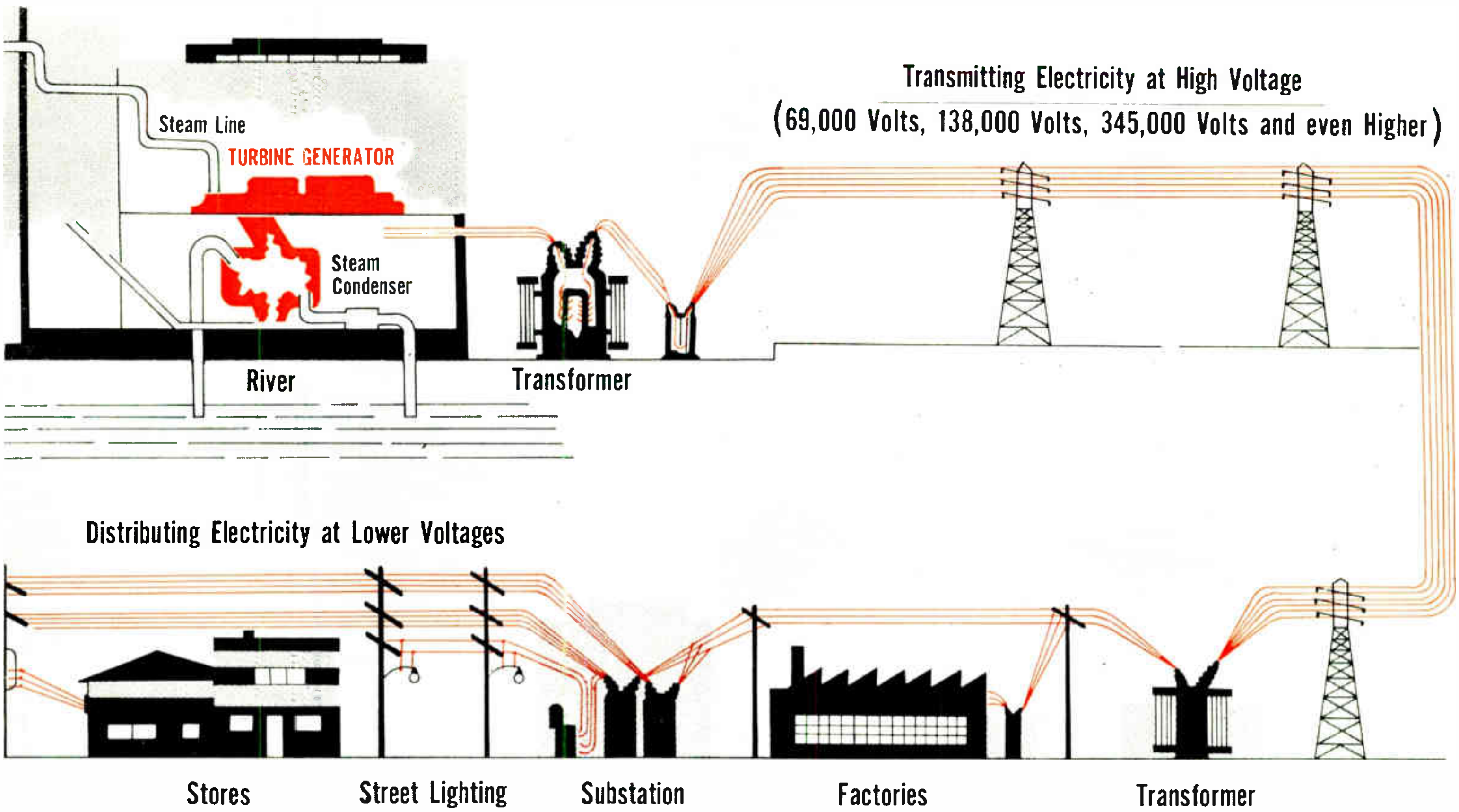
Nowhere else in the world is this tremendous use of electric power duplicated or even closely approached. With only six percent of the world's population, the United States generates 40 percent of the world's electric power. In 1960, its power output exceeded the combined output of the next six countries—Russia, United Kingdom, Canada, Japan, West Germany and France.

A vision of what was in store was in Edison's mind when he put the first central station generator in operation in 1882. Asked by a reporter for the *New York Times* how long he thought the generators would keep running, Edison replied confidently, "Forever, unless stopped by an earthquake."

World's Most Important Single Machine

This great development would never have materialized without the turbine-generator. A modern steam

Generating Electricity,



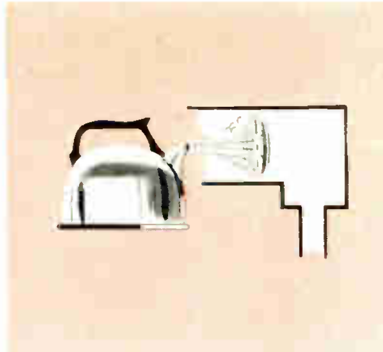
In 50 million homes in the United States, the magic of electric power is available at the flick of a switch.

turbine-generator produces up to 50 times as much power as a piston-engine generator of the same physical size, at a fraction of the cost. Without it, the utility companies that provide the great bulk of the country's electric power, would be unable to function as they do.

Electric current can be made with a loop of wire and an ordinary horseshoe magnet by holding the loop between the ends of the magnet and turning it, thus cutting through the magnetic lines of flux. The faster the loop is turned, the more lines of flux will be cut and the more current will be made, though with a single loop of wire, the amount will be infinitesimal.

In a modern power plant, the turbine is the prime mover which provides the rotary motion. The generator is essentially a magnet and coil but constructed on a vastly more complex and efficient scale. The outer shell of a generator is a hollow steel cylinder, called the stator, which contains groups of insulated copper conductors. The generator rotor, coupled to the turbine rotor, is placed inside the stator. On the generator rotor is a series of wire coils so arranged that the passage of a direct current through them produces a series of magnetic north and south poles on the rotor surface. As the rotor spins, the magnetic flow at the poles sweeps around the inner surface of the stator, cutting the stator conductors with magnetic lines of force, thus generating current.

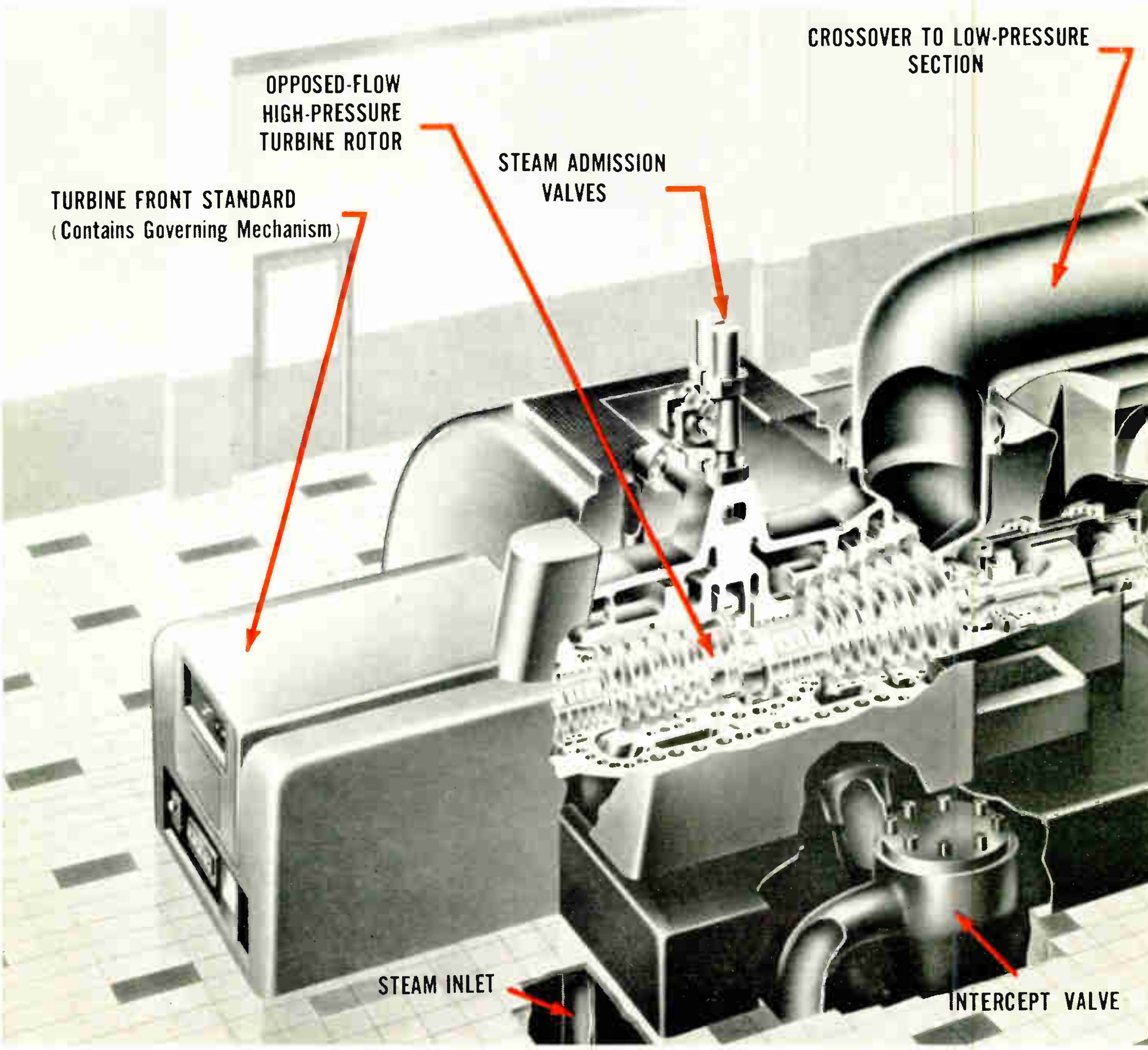
There are two kinds of turbines which supply practically all of our



electric power, the steam turbine and the hydraulic or "hydro" turbine. Of these, the steam turbine accounts for more than 80 percent of the nation's electric power load—a good reason for calling it "the world's most important single machine.

Principle of the Turbine

A turbine is a machine to convert the force of a moving fluid such as water, air, or steam into rotary motion of a shaft. The principle was known in the earliest days of civili-



zation. Windmills and water wheels are familiar examples. Hero of Alexandria is said to have operated a kind of pinwheel by steam from a kettle in 120 BC. Attempts to develop a practical steam turbine were undertaken soon after the successful development of the piston steam engine. But the metalworking of that period was too crude to permit the making of a practical steam turbine.

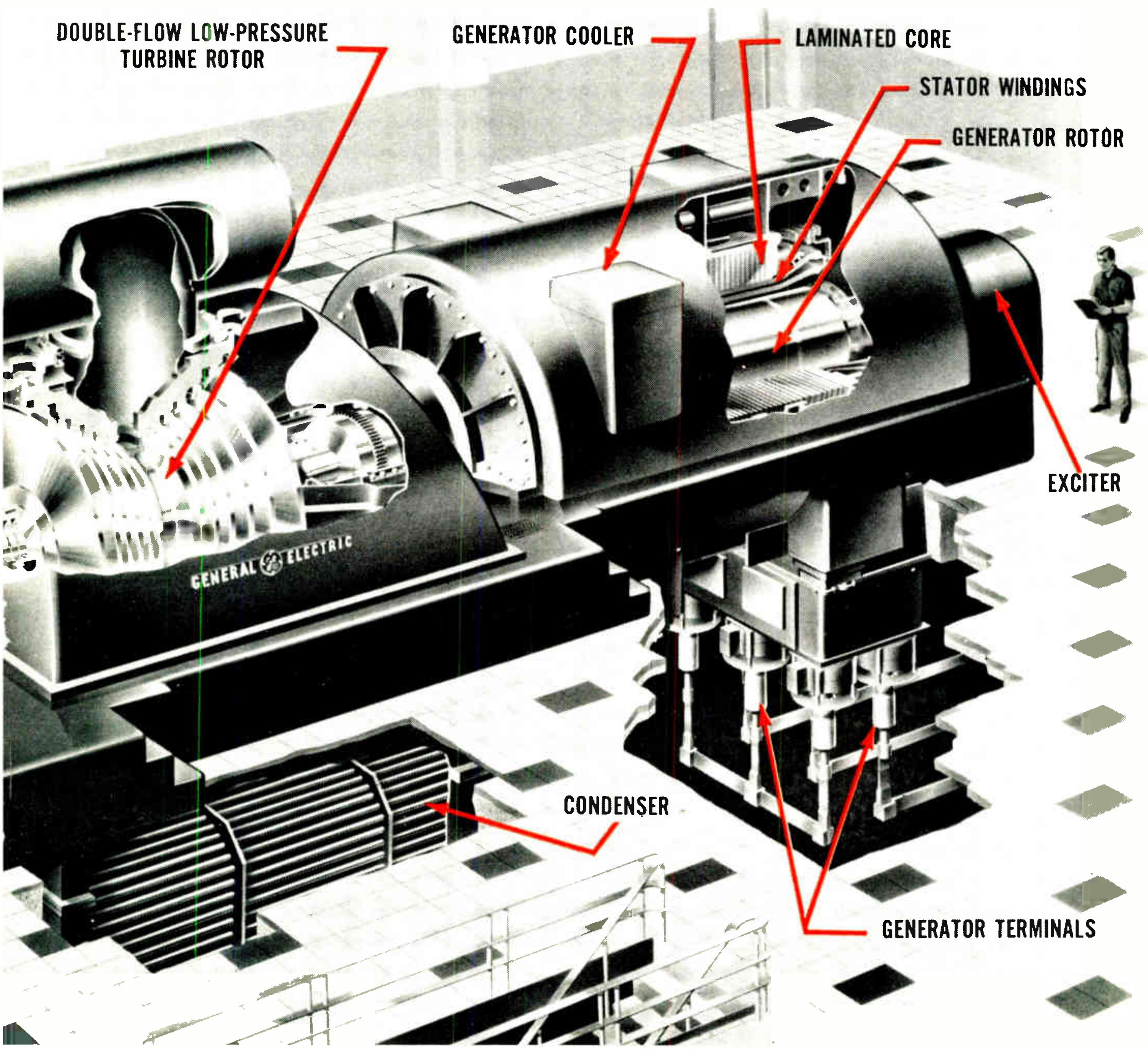
Men kept struggling with the problem, however, and in the 1880's and 1890's began to meet with some success. Charles Parsons in England developed a small steam turbine to drive electric generators on board ships. An American, Charles Curtis, designed a turbine of somewhat different type in 1896.

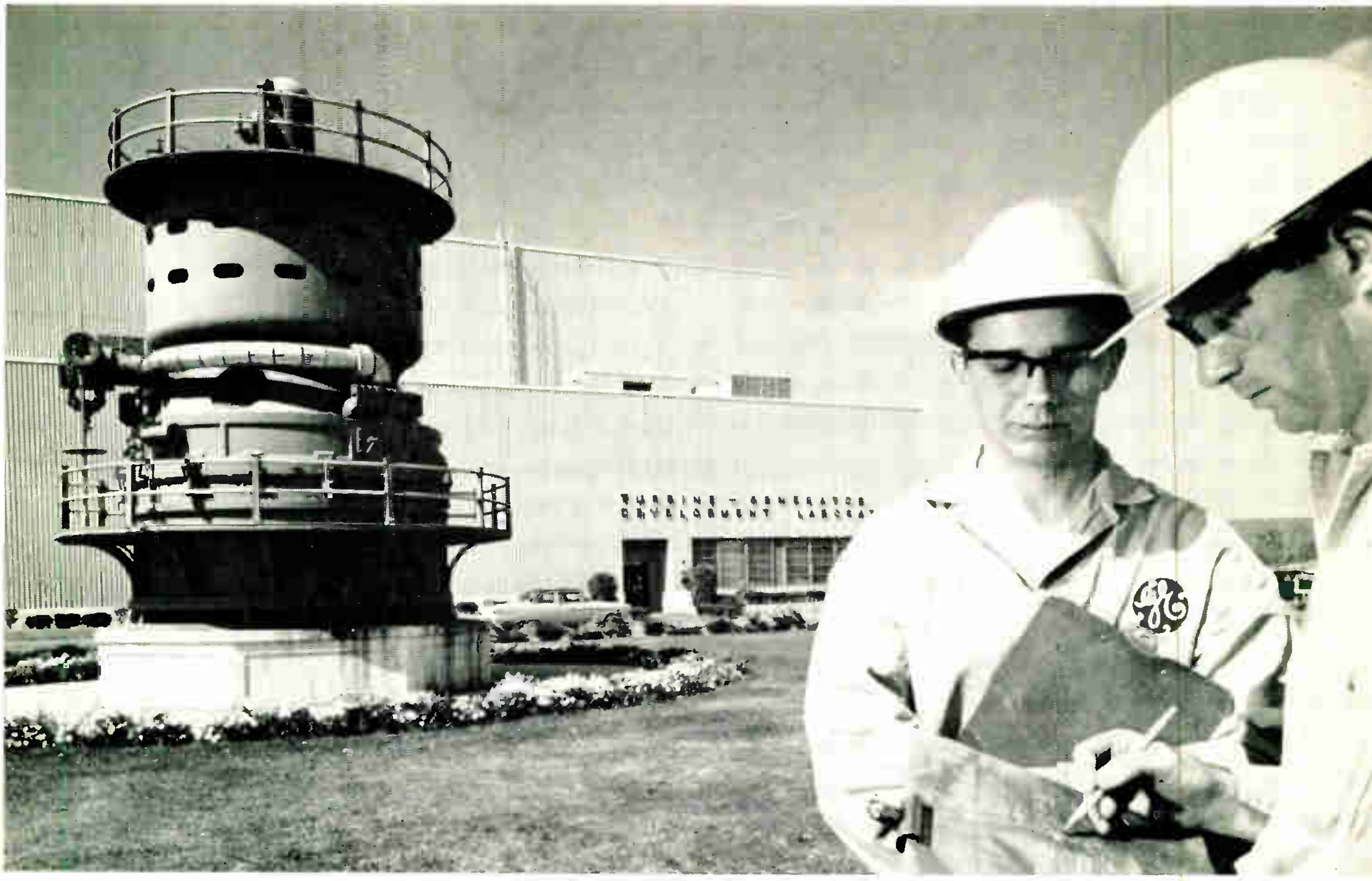
This had concave steel blades known as buckets placed around the circumference of a large disk inside a metal housing. High pressure steam directed against these buckets caused rapid rotation of the disk and the shaft to which it was attached. Condensing the steam after use created a vacuum that added to the effective steam pressure.

Curtis had a patent on this idea, but he had no money or facilities to develop it. So he came to Schenectady, N. Y. with a traveling bag full of plans and offered his invention to the General Electric Company.

First Successful Turbine-Generator

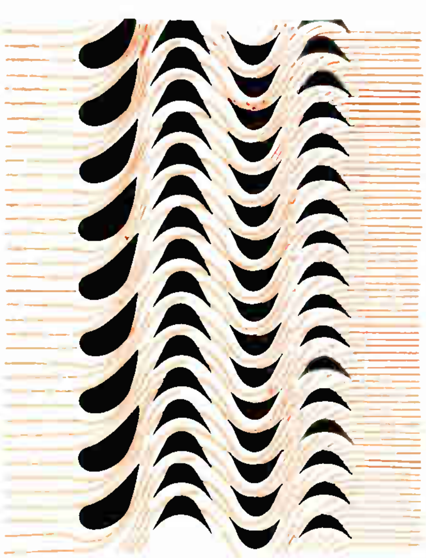
The new turbine represented a radical departure from the piston engines then used to drive electric generators, and it meant a considerable gamble in time and money. But Company officials decided to take a chance and build the Curtis machine.





The original 5000-kilowatt turbine-generator for Chicago has been returned to Schenectady where it stands as a monument to the courage of its builders and an inspiration to their successors.

Steam flow through turbine.
Based on "Steam Turbines," a special report, POWER, June, 1962



The first small, crude model took shape in a pit dug in the factory yard. None of the machinists had ever worked on such a device before, and they were somewhat fearful of a precision machine which was designed to run at high speeds. Today, turbine parts are machined more precisely than many fine watches. But such precision was unknown then, and Curtis tested his turbine with its wheels spinning dangerously near the heavy metal casing.

In test after test, the turbine failed to match the performance of piston engines, and the trials were almost abandoned. But a young General Electric engineer, W. L. R. Emmett, believed the turbine principle could be made to work. He undertook to redesign the machine, making important changes in the arrangement of buckets and nozzles.

By November of 1901, a Curtis turbine-generator rated at 500 kilowatts with a speed of 1200 revolutions per minute was operating successfully and was put to work in the General Electric plant at Schenectady.

The problem now was to make a turbine powerful enough and efficient enough to better the performance of the huge piston engines—as powerful as 7000 horsepower—in some power stations. General Electric received an order for a 5000-kilowatt turbine-generator from Commonwealth Edison of Chicago, and both companies staked their reputation on the performance of this new powermaker. It was not only the first of its kind, but also the most powerful electric power generation equipment in the world. Yet it required only one-tenth the space, weighed one-eighth and cost one-third as much as a piston-engine generator of equivalent power. The success of this unit attracted the attention of power generation men all over the world, and orders for steam turbine-generators began to pour in.

The Commonwealth Edison unit

of 1903 was a great advance over piston engines. But six years later, it was obsolete. In 1909, it was replaced by a new turbine-generator which was more than twice as powerful, yet which fitted on the original foundations and used steam from the same boilers. The original unit was returned to the General Electric plant at Schenectady where it stands in Turbine Park in front of the Turbine-Generator Development Laboratory . . . a monument to the courage of the men who built it, and an inspiration to their successors.

Inside the Turbine

The turbine is simple in principle, but its efficient operation depends upon its being built with extreme care and accuracy. Underneath the turbine's metal casing is a roaring inferno. Heated in a boiler, steam rushes into the typical turbine at a speed of more than 1000 miles an hour and at temperatures of over 1000 degrees. At tremendous pressure it passes through a ring of nozzles and hits the first circular row of curved buckets. The impact of the steam moves the buckets sideways and starts the rotor turning. The steam rushes on through succeeding sets of nozzles and rows of buckets, adding to the spinning of the rotor.

In less than 1/30 of a second, the hot steam has hurtled through as many as 24 wheels, hitting some 5000 buckets, spinning them around at thousands of revolutions per minute. In fact, the first man-made things to go faster than the speed of sound were the tips of the last stage buckets on a spinning turbine rotor.

This split-second journey literally exhausts the steam. As it charged out of the first ring of nozzles, it was hot enough to turn the buckets red. When it leaves the turbine, it is cooler than the human body—a temperature drop of about 1000 degrees. And its tremendous power is gone. It entered the turbine at a pressure of 2000 pounds or more per square inch. During its forward thrust through the steam bath, it expanded to a thousand times its original volume, and it leaves the last bucket wheel at a lower pressure than the air we breathe.

This is not the end of the steam's usefulness. Leaving the turbine, it moves on into a condenser where it is cooled until it turns to water. This condensing process creates a vacuum which draws more steam from the turbine. The water then returns to the boiler to be reheated and used again, thus completing a cycle that is repeated over and over.

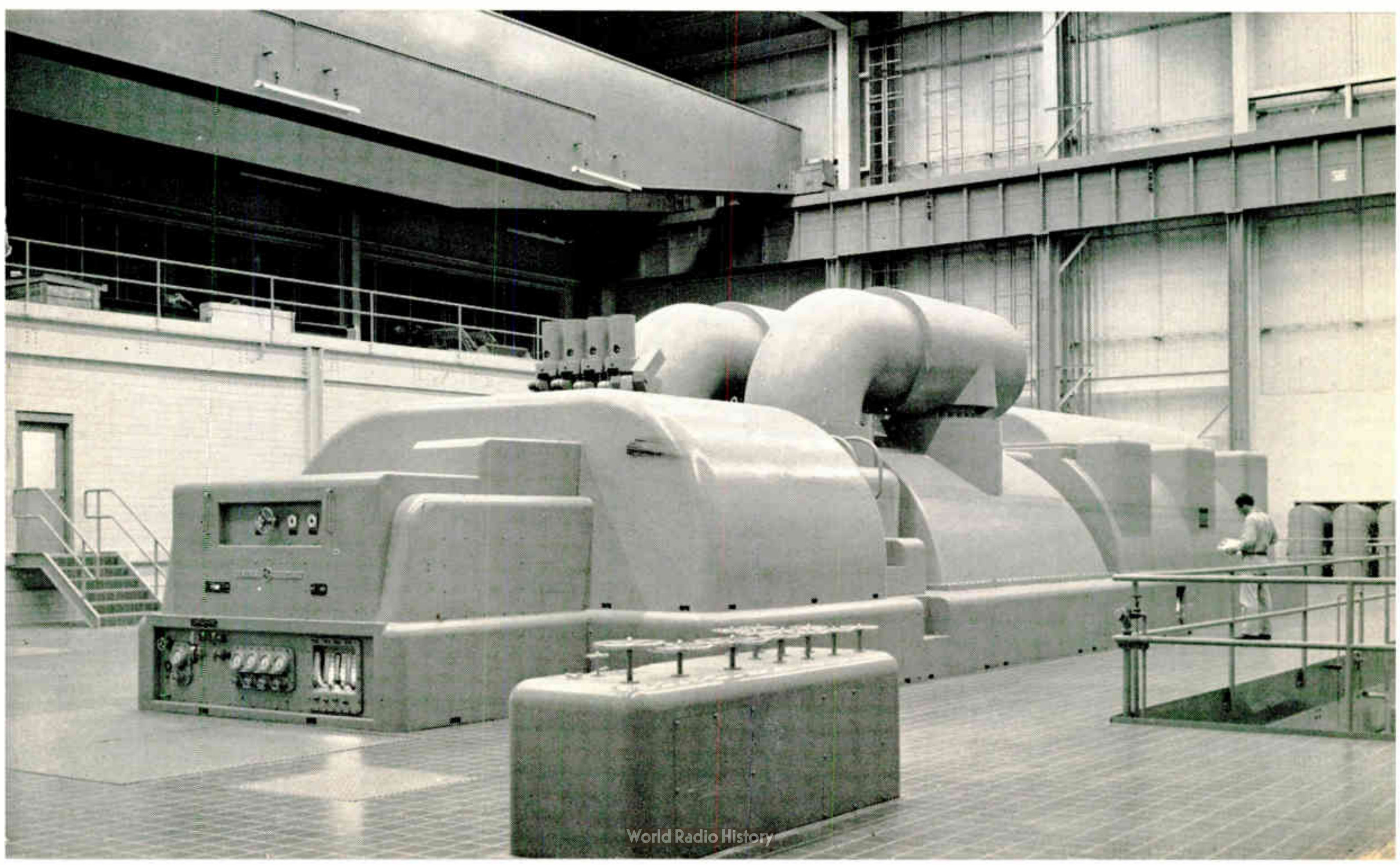
Efficiency a Vital Factor

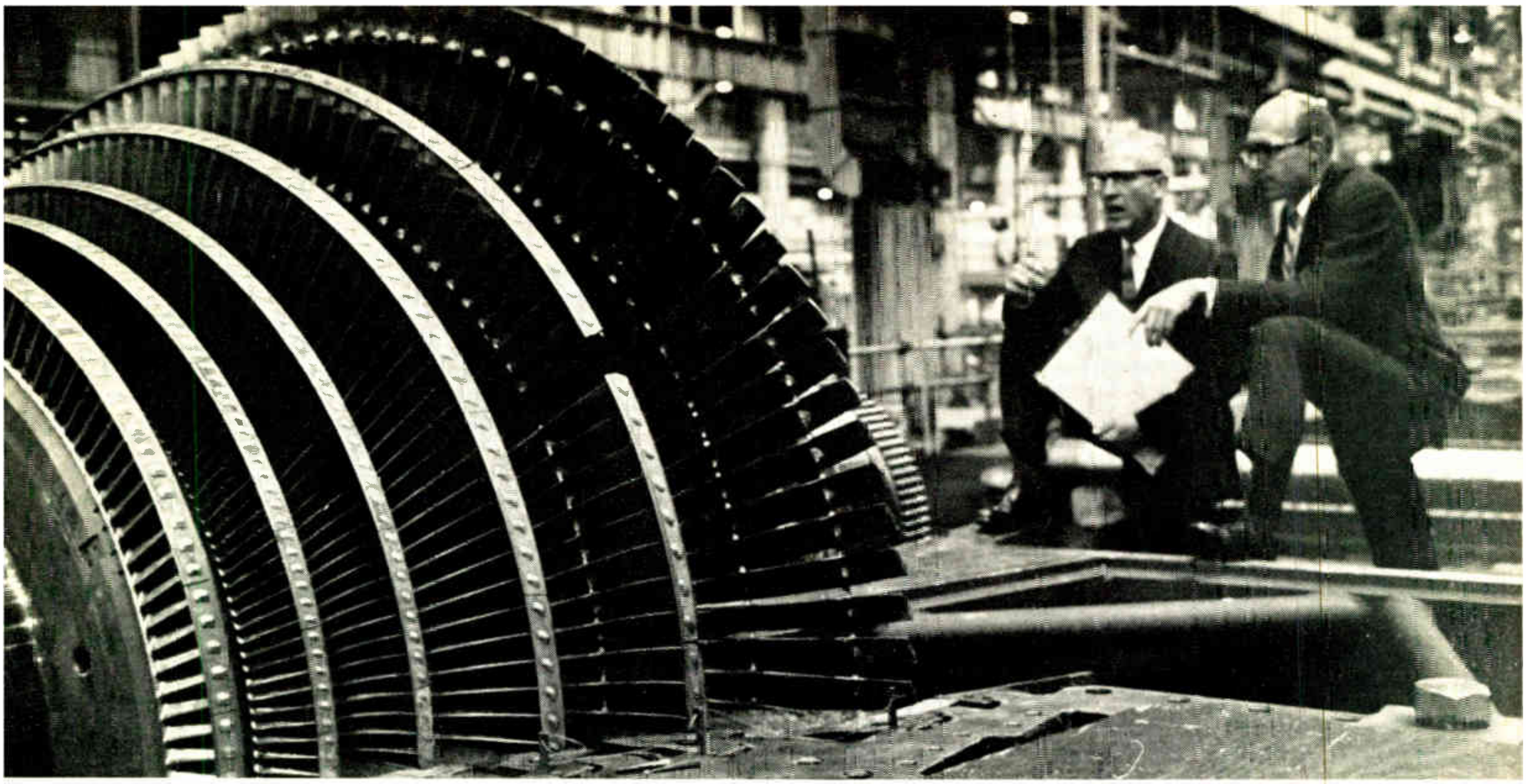
A turbine must first of all be efficient. A large unit may consume as much as a million tons of coal in a year. During its lifetime, its fuel cost may be as much as 30 to 40 times its purchase cost. If it is the least bit inefficient, it can wastefully burn up the equivalent of its own price in this time.

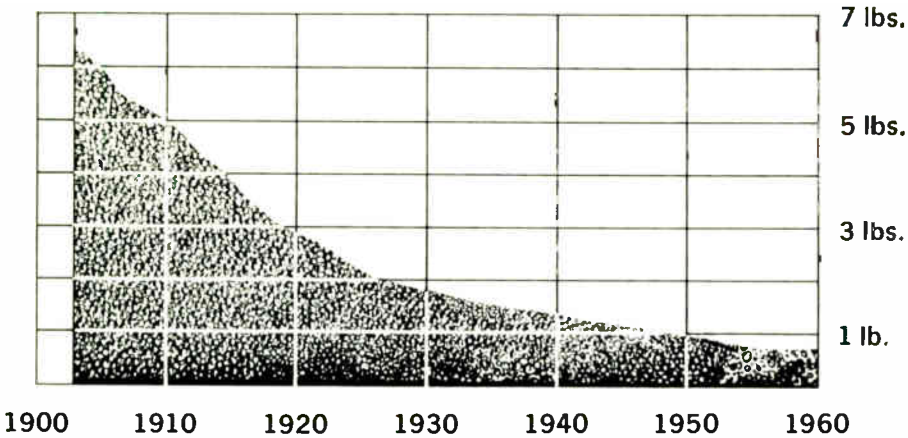
But, thanks to the unceasing efforts of the design engineers, fuel consumption has been steadily reduced. In 1900, it took nearly seven pounds of coal to produce one kilowatt-hour of electricity. Today, less than one pound is needed.

This is the reason for the multiwheel design of the turbine—to

Building a steam turbine-generator, such as this one, is both huge undertaking and delicate art. It cannot be mass-produced. Each one represents more than a year of planning, engineering, and manufacturing.







It now takes less than a pound of coal to generate one kw-hr of electric energy. It once took more than six pounds. Every time the amount of coal needed to produce a kw-hr is lowered by even a fraction of an ounce, the savings can mount to millions of dollars for the nation's homes and industries. It's continuous effort like this that keeps electricity the greatest bargain in America.

squeeze the last ounce of energy out of the steam. It is the combined effect of steam pressure on row after row of buckets that creates the high rotor speed.

There is a reason for the different size and length of the turbine buckets, too. The steam impinges on the first row of buckets at very high pressure. Its density is so great that it needs only to meet a small surface to move it. But as it moves on and loses its density, larger and larger surfaces are required to utilize its waning power. That is why the first row of high pressure buckets are small with succeeding rows of buckets gradually increasing in size.

The shape and set of the buckets are particularly important. The steam must hit the buckets at an angle which will utilize the pressure to the utmost. And as it speeds on, it must hit succeeding rows of buckets at the optimum angle. For this reason, stationary rings of nozzles are placed between bucket wheels. As the steam glances off one row of buckets, it enters the nozzles where it is turned in the opposite direction. The nozzles guide it back to the correct striking angle. Years of observing buckets in wind tunnel tests have improved their design and placement, and have streamlined the turbine's interior.

It has taken engineers and metallurgists years of development work experimenting with new alloys, to produce metals strong enough to resist the heat and blasting action encountered in the steam path of a turbine. An engineer once remarked that, if making turbine buckets of gold would increase the efficiency of the turbine, the electric power industry could not afford to use any other metal. Fortunately, for everybody, gold does not have the characteristics desirable for this purpose.

engineering the powermakers

To an engineer, even an amazing achievement must be bettered.

Measured by today's standards, the first steam turbine-generator—a genuine achievement in its own right—was a clumsy machine. But it was the starting point to low-cost electricity, one of the principal wellsprings of our national prosperity.

For more than six decades, engineers have striven to improve the design of turbine-generators and the other power-station equipment such as boilers and auxiliaries. It is a matter of record that electrical and mechanical engineers, metallurgists, experts in heat transfer, and scientists in other fields — working together — have increased the efficiency and economy of electric power generation.

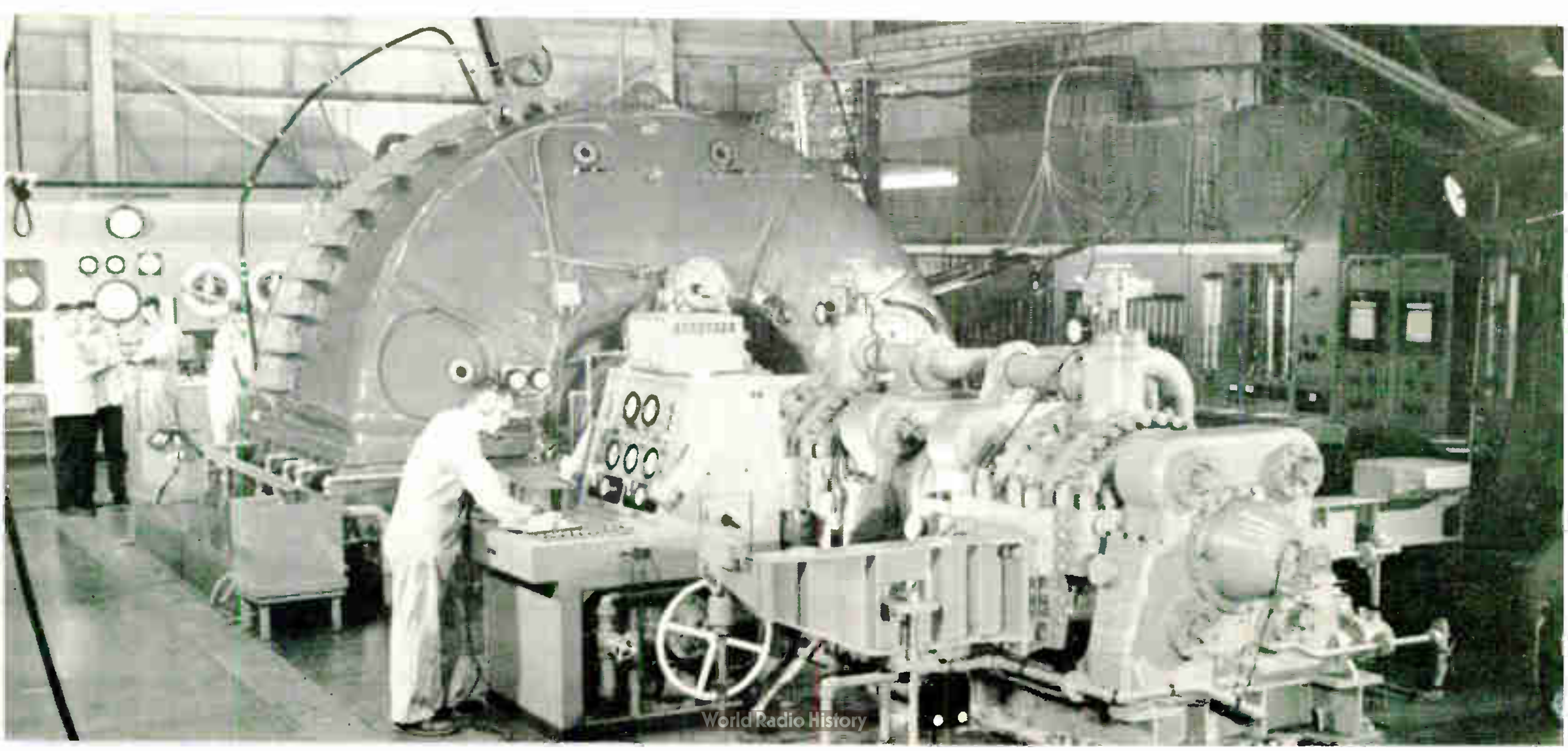
Since coal is the major expense in making electricity, the major problem has been: more kilowatt-hours from every pound. It takes about one billion pounds each year to produce the steam necessary to run a typical, modern large steam turbine-generator; so every time the amount of coal needed to produce a kw-hr is lowered by a fraction of an ounce, the savings can amount to millions of dollars for the nation's homes and industries.

Finding ways to improve performance is the engineer's job. His successful meeting of challenges has much to do with the shaping of our country's future.

Top. Since the goal is years of uninterrupted service, each component must undergo severe tests. These engineers are testing an oil-cooler system.

Center. The model is an early stage of turbine-generator engineering. The complex parts of the completed unit must fit together with the precision of a fine watch.

Below. When the power demands are highest, the turbine works the hardest. It's the function of the water brake test-facility to determine future performance.

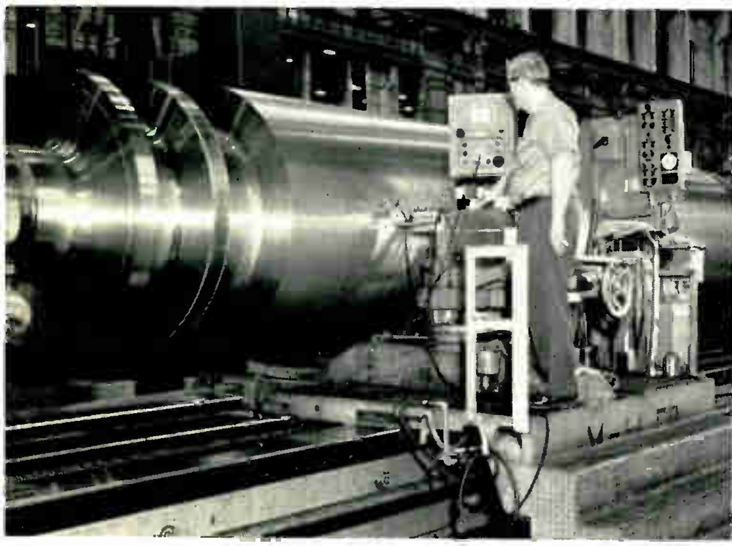


the art of turbine building

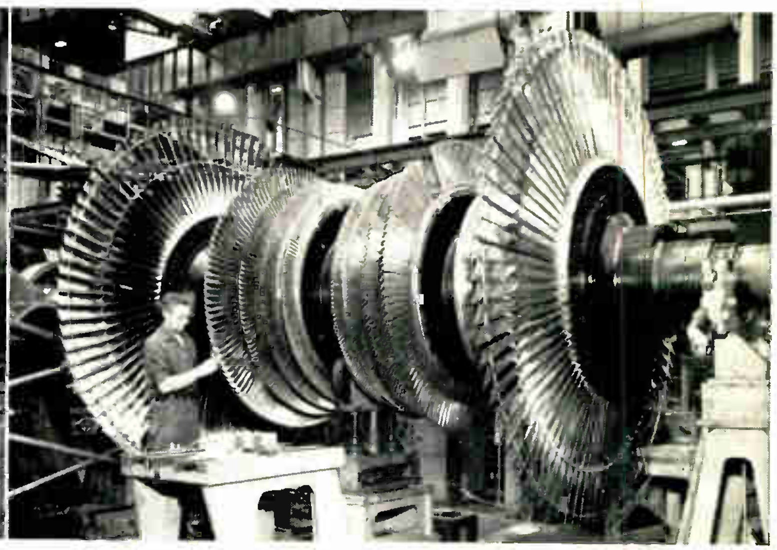
Building a large turbine is at once a mammoth undertaking and a delicate art. There can be no mass production of turbines. These huge powermakers are built to order to fill particular power requirements. Anywhere from one and a half to three years of planning, engineering and manufacturing goes into the building of each, depending on its complexity and size.

After the turbine's design is ready, castings of the metal parts or shells must be made. Wooden patterns of castings are made, assembled—with as much precision as if they were the shells themselves. With the patterns as a guide, the huge metal shells are cast, then machined to a minute fraction of an inch. Assembly and testing follow. X-ray and ultrasonic tests are made to ensure that there are not any hidden flaws in the metal. A turbine must be able to stand up to forty years of constant high-speed, high-temperature punishment, and such treatment can magnify even the smallest imperfection. Tests assure that the turbine can deliver the required power and that it is in perfect balance with no destructive vibrations.

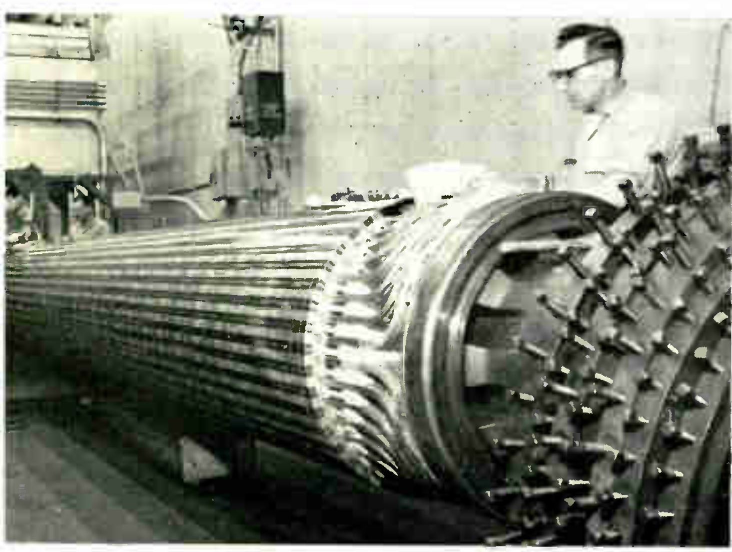
This 115-ton generator rotor will spin at great speed. Ultrasonic testing uncovers any hidden flaws in massive forging.



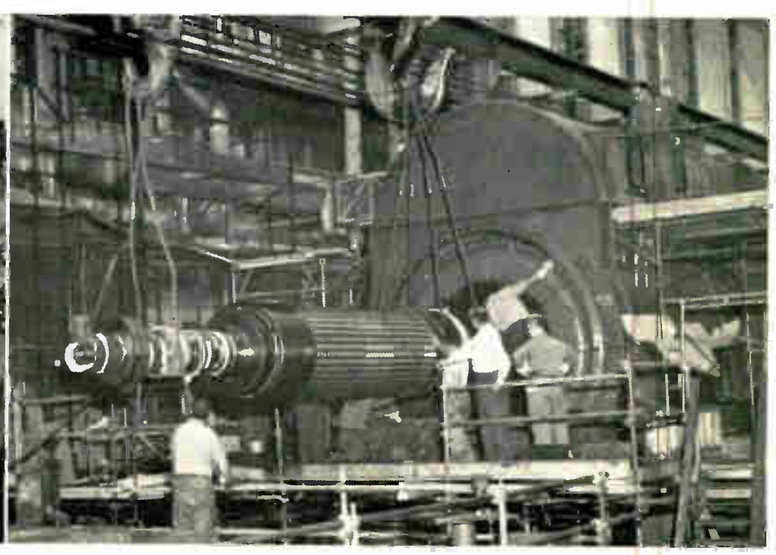
Thousands of the rotor's gleaming buckets will catch the force of live steam . . . will do their work, for years, in a roaring inferno.

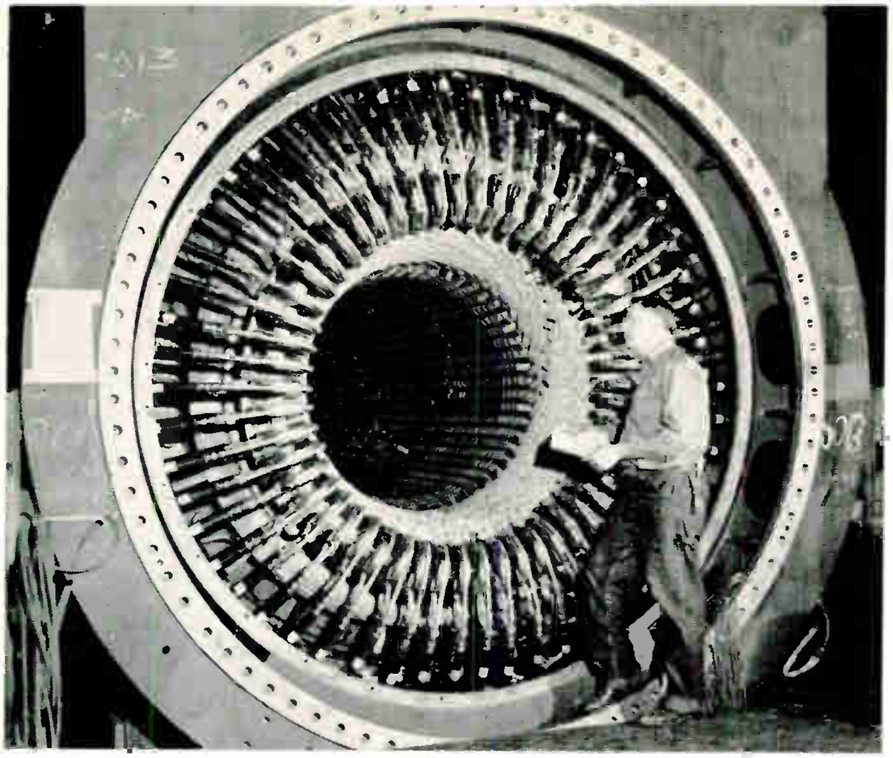


This is the rotor for a hydrogen-cooled generator during the process of winding. Preshaped copper coils are inserted in slots.



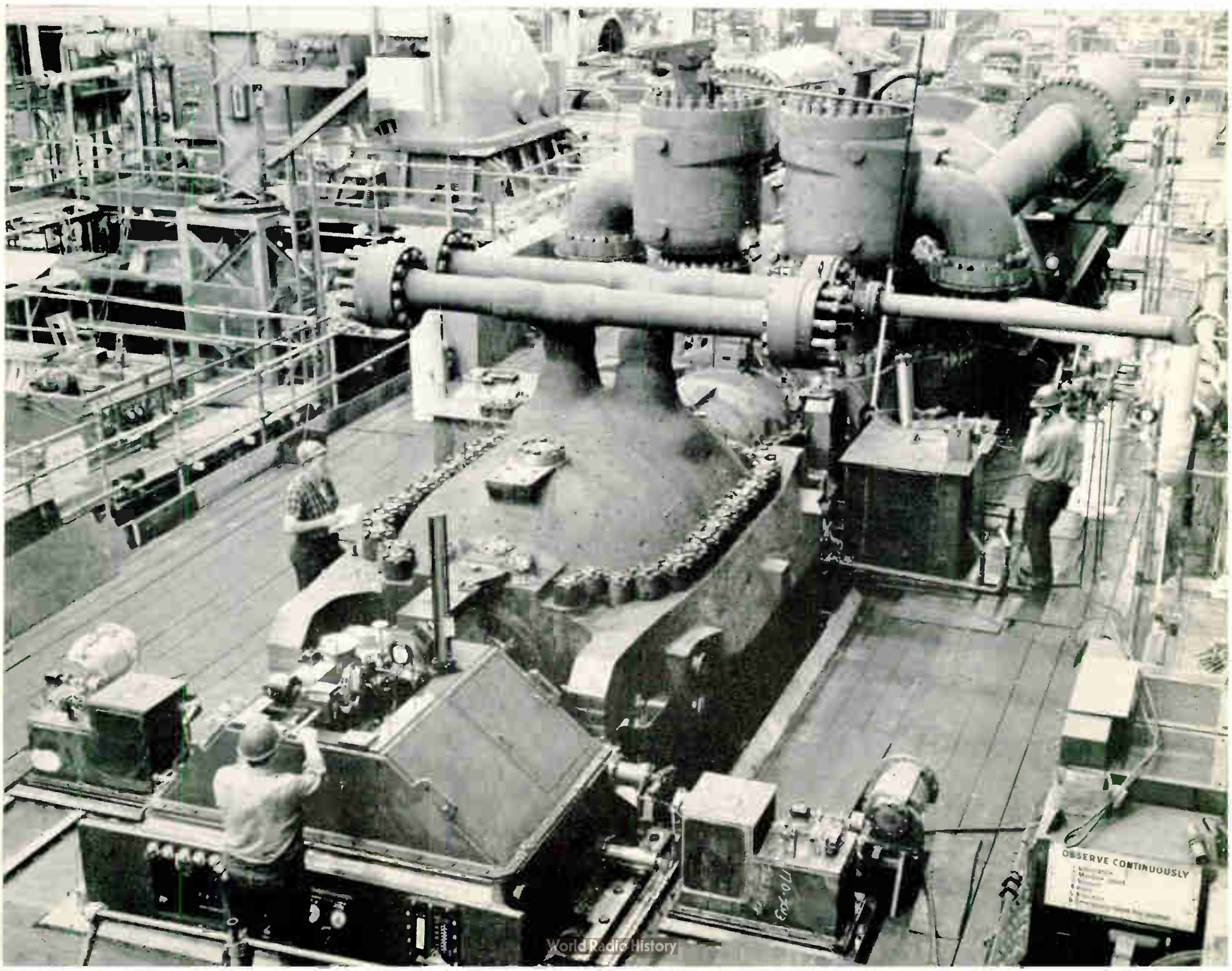
Completed rotor enters collector end of a generator stator. The turbine and the generator are assembled in factory for checking.





Left. The generator assembler makes a final check of the liquid cooling hose connections of a stator, prior to its being moved to test area.

Below. Since the huge powermaker is engineered and manufactured to meet particular power requirements, up to three years may have been spent before it is ready for assembly. Here that time has come, and it's being thoroughly checked before delivery to the customer.



turbines at sea

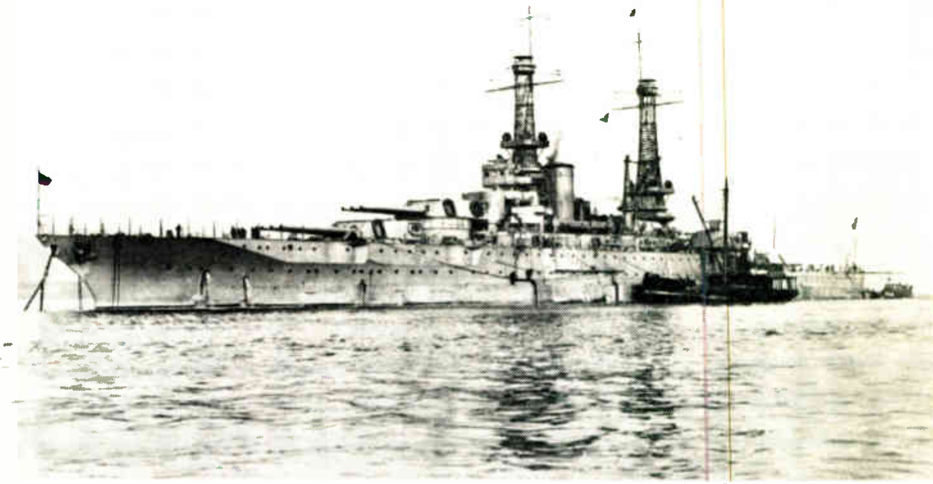
Turbines play an important part in ship propulsion as well as land power generation. The success of the first steam turbine-generators for Commonwealth Edison suggested their use on shipboard in conjunction with electric motors to turn the propellers. By this means, more power could be produced in proportion to the weight of machinery, and less fuel used than with the conventional, piston-engine, ship propulsion equipment.

Electric drive was tried first in 1913 on a 20,000-ton collier, the USS *Jupiter*. It worked so well that, in 1917, it was adopted for the battleship *New Mexico*, then in the design stage. Here, too, it performed in a highly satisfactory manner.

Electric propulsion machinery was then proposed for a group of very large battle cruisers designed for a speed of 34 knots. Construction of this machinery was halted during World War I, but eventually, two of the ships were completed as aircraft carriers which performed valiant service in World War II.

In 1936, a new type of ship propulsion was developed utilizing a compact, high-pressure, high-speed steam turbine geared directly to the propeller shaft. This set the style for the great new fleet that the United States was just starting to build. New battleships, fast cruisers, aircraft carriers and a host of destroyers were all equipped with geared-turbine propulsion equipment.

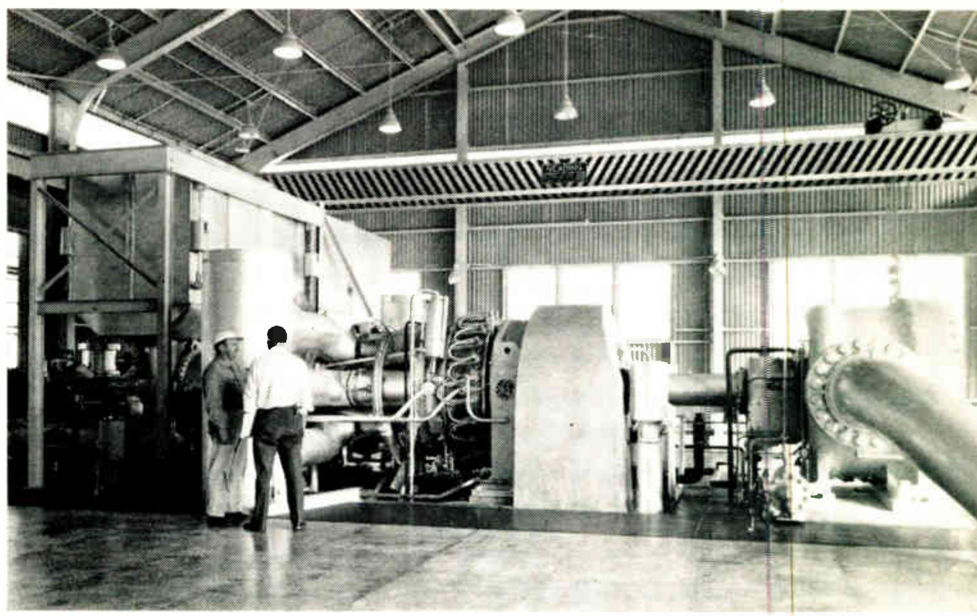
When the United States entered actively into World War II, the shipbuilding program was greatly expanded. Turbine and turbine-generators were supplied for hundreds of destroyers, cruisers, six battleships, ten aircraft carriers, destroyer escorts, cargo ships and oil tankers. By the end of the war, General Electric alone had built 27 million horsepower of turbine-propulsion equipment for the Navy, the equivalent of all the turbine equipment which the company had built for the power industry since the construction of the original turbine-generator.



Navy Department Photo

Above. The electrically propelled **USS New Mexico** was launched in 1917. During World War II, 483 Naval ships and 848 Merchant Marine ships used General Electric turbine-propulsion equipment.

Below. The gas turbine now performs many industrial operations, like driving a centrifugal compressor in a gas pumping station.



how the gas turbine works

The gas turbine operates on a cycle which is somewhat akin to that of the piston engine. Air is taken in, compressed, and delivered to a combustion chamber where fuel is added and burned. Heat expands the gases, forcing them at high velocity against the blades of a turbine wheel, after which the gases flow out of the exhaust.

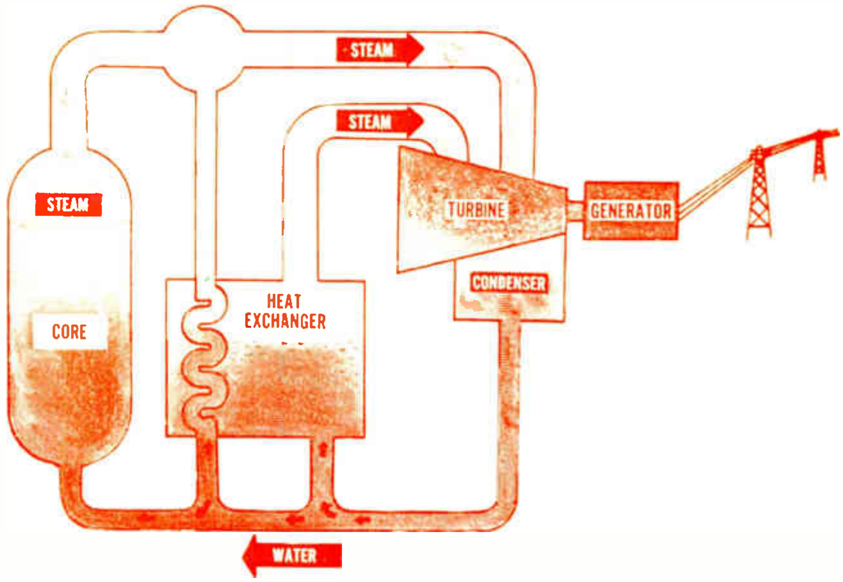
These gas turbines are successfully performing a variety of industrial operations. Their ability to operate without a supply of water for conversion into steam, and without cooling water to condense the steam, make them advantageous under certain circumstances. The high temperature of the exhaust gases can be utilized to provide heat for industrial processes. When a gas turbine is used in conjunction with a steam turbine, the exhaust gases can be used to heat boilers to provide the steam.

the atom and the turbine

A new chapter in electrical progress opened with the development of atomic power. Atom-produced electricity is, of course, no different from electricity generated in conventional plants. In a typical electric power plant, fuel is burned, changing the water in the boiler into steam. The steam drives a turbine that turns a generator to produce the electricity. In an atomic power plant, a nuclear reactor takes the place of the fuel combustion in the making of steam. The operation of the turbine and the generator remain the same.

At the beginning of 1962, there were five atomic power plants in operation in the United States. Ten additional plants were in the design or construction stage. None of the five completed plants was then producing electricity at a cost as low as that of conventional plants burning fossil fuels such as gas, coal or fuel oil. As experience is gained, however, the cost of atomic power is being reduced, and further reductions are expected until costs become competitive in areas where fossil fuels are expensive.

The conventional fossil fuels will be in abundant supply in the United States for years to come. But they are not inexhaustible, and with the tremendous increase in the use of electricity expected in future years, there will come a time of growing reliance upon fissionable materials as an energy source. Estimates have been made that the energy content of known reserves of fissionable materials is about twenty times that of the world's fossil fuel reserves. Conscious of this, the electric power industry, including both utility companies and manufacturers, is conducting a comprehensive program of atomic power development.



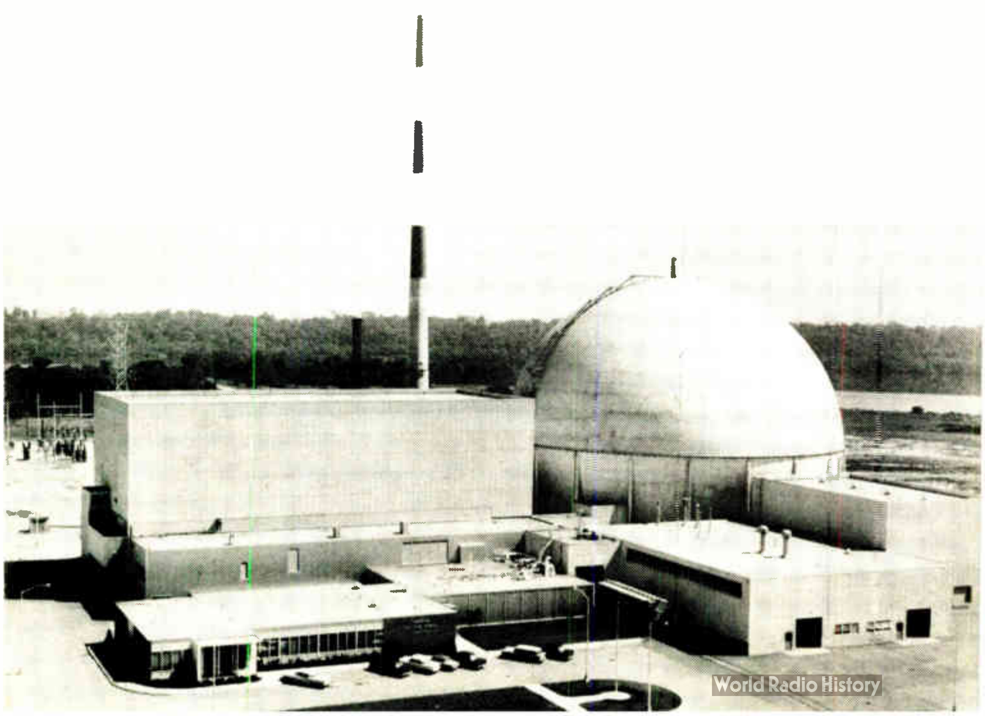
In a dual-cycle reactor, the atomic fission process takes place in the core of the reactor releasing tremendous heat. Water surrounding the core boils, forming steam that goes into the turbine. At the same time that steam comes out of the reactor, very hot water comes out and goes to a heat exchanger where it gives up heat to make more steam. Secondary steam, at a lower pressure, also goes to the turbine.

What of the Future?

The electrical industry in the United States has been growing at a phenomenal rate. In the past, it has about doubled its generating capacity in every ten-year period since abundant electricity became available. There is every reason to believe that this rate of growth will continue or even increase somewhat. By the 1970's the electric industry will be generating trillions of kilowatt hours, not billions. To produce this amount of power, a huge increase in generating capacity will be required.

Larger and more efficient steam turbine-generators will provide the major part of this additional capacity. New designs and new materials, higher temperatures and higher pressures will be required. Additional hydro-electric projects will be developed too, but there are not enough new water sources available to keep pace with the expanding demand for electricity. Nuclear fission may replace conventional fuel combustion in producing steam for the new turbines, but the turbine generator itself will remain the muscle and sinew of progress.

The Dresden Station supplies Chicago with 200,000-kw of electric power from the atom.



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