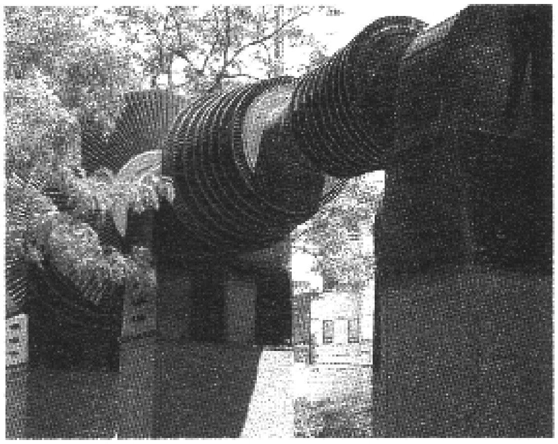
Philo 6 Steam - Electric Generating Unit

Designated a
Historic Mechanical Engineering Landmark
By The American Society of Mechanical Engineers

Columbus, Ohio
August 7, 2003



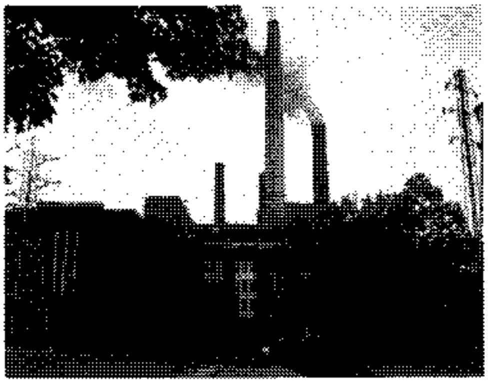
ASME International

ENGINEERING BREAKTHROUGHS AT PHILO 6 FUEL UNPRECEDENTED LEVELS OF GENERATING EFFICIENCY

- *Philo 6, owned and operated by American Electric Power (AEP), pioneered mechanical engineering innovations that vastly improved power plant generating efficiency.*
- *Innovations included use of steam of 'supercritical' pressure and temperature, steam that underwent two reheatings to improve thermal efficiency and improvements in materials and other components.*
- *Advances were made possible through the efforts of AEP, Babcock & Wilcox Co. (steam generator design) and General Electric (steam turbine design).*
- *Large coal fired steams units built after Philo 6 incorporated one or more of the technologies introduced by this pioneering unit.*
- *Many generating units using these technologies remain in operation, producing vast supplies of electricity at lower cost than would be possible otherwise.*
- *Located in southeastern Ohio, the unit began operation in 1957 and was retired in 1979.*
- *On the 50th anniversary of the announcement of its construction, Philo 6 is being designated a Historic Mechanical Engineering Landmark by ASME International.*

On the cover: *Two of the three mtors from Philo 6 steam turbine in a sculpture, created in 1983, outside the headquarters building of American Electric Power in Columbus, Ohio. The first and second rebeat turbine rotor is on the right end; the double-flow low-pressure turbine rotor is on the left end (George Greenamyer, sculptor)*

AEP *The AEP oval was the company logo from 1985 to 1987, prior to 1958 the company's name was American Gas and Electric Co.*



Right: *The Philo Plant in Philo, Ohio, as it appeared in 1957, Unit 6 is in the foreground, with the tallest stack.*

ADVANCEMENT OF A TECHNOLOGY

'SUPERCRITICAL' BARRIER BROKEN AT PHILO

Painstaking research to advance the technology of electric power generation came to a head in 1957 when Unit 6 began operation at the coal-fired Philo Plant in Ohio. This steam-electric generating unit operated with steam at a pressure and temperature significantly higher than any other utility power plant in the world at the time. Philo 6 achieved major improvements in thermal efficiency due to its use of steam — above the “critical point” in pressure and temperature — coupled with other mechanical engineering innovations such as “double reheat.” (Both of these terms are described later.)

These improvements led to a significant reduction in fuel consumption, thereby reducing the cost of producing electricity. Experience gained from the engineering, design, construction and operation of Philo 6 spawned a new generation of larger, more efficient units. Most of these subsequent power plants, built on this pioneering technology, continue in service worldwide today.

Many engineering disciplines — mechanical, electrical, chemical, civil, environmental and others — collaborated in the development of Philo 6. No single engineering discipline or practitioner alone was responsible for its success. Credit belongs to the team that included American Electric Power (AEP)[1], the utility owner, The Babcock & Wilcox Co. (B&W), which manufactured the steam generator, General Electric Co. (GE), which manufactured the steam turbine, and a host of other manufacturers and suppliers.

Philo 6 ran successfully from 1957 to 1975 when it was mothballed. In 1979 Philo 6 was officially retired. This innovative unit was demolished in 1983 along with the rest of the 60-year-old Philo Plant. However, the three rotors from the Philo 6 steam turbine were preserved and remain a tribute to the forward-thinking engineers who created this pioneering unit. Two of these turbine rotors[2] were incorporated in a sculpture at AEP headquarters in Columbus, Ohio, and serve as symbolic representation, or proxy, for Philo 6, which has been designated a Historic Mechanical Engineering Landmark by ASME International. This designation occurs on the 50th anniversary of AEP’s announcement to build Philo 6.

The leap from “subcritical” to “supercritical” steam at Philo 6 in the power generation industry was comparable to the jump from subsonic to supersonic flight, made 10 years earlier in the aviation industry. Breaking the critical steam barrier presented many engineering challenges analogous to those surmounted in breaking the sound barrier:

STEAM HAS BEEN AT THE HEART OF ELECTRIC GENERATION

The generation of electric power with steam dates back almost to the beginning of the electric utility industry. The first central power plant (one in which electricity is generated at a central station and then distributed to many individual customers) was Thomas Edison’s Pearl Street Station in New York City. On Sept. 4, 1882, that station began supplying electric power to 59 customers in its immediate neighborhood. At Pearl Street, Edison utilized steam engines to drive dynamos that produced electric power[3]. The steam was produced in boilers heated by coal.

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[1] AEP is the largest electricity generator in the United States. From its founding in 1906 until May 1958, the company’s name was American Gas and Electric (AG&E). In this brochure, AEP, its current name, is used when referring to the company both before and after the name change.

[2] The third turbine rotor is on display at AEP’s Central Machine Shop in South Charleston, West Virginia.

[3] Jumbo No.9, one of the steam engines and dynamos from the Peal Street Station, was subsequently relocated to Dearborn, Michigan, and put on display at Greenfield Village. In 1980 Jumbo No.9 was designated a Historic Mechanical Engineering Landmark by ASME.

The basic concept of generating electricity from heat (thermal) energy through the use of steam has not changed since the days of Pearl Street well over a century ago. What has changed is the technology of implementing this basic concept. As a result, steam power plants grew progressively larger, more complex and significantly more efficient in converting thermal energy into electricity. Higher efficiency means lower-cost electricity and less impact on the environment since less fuel is required to produce the same quantity of electricity.

Advances in power plants since Pearl Street were characterized by the introduction of new machines into the process. Notably, at the turn of the 20th century the steam turbine replaced the steam engine, and the alternating current generator replaced the direct current dynamo. The idea of preheating the water before it entered the boiler was developed from its rudimentary beginning at Pearl Street. The concept of reheating the steam after it passed through part of the turbine was begun in the mid-1920s to enhance efficiency. That concept was extended in 1957 at Philo 6 to reheating the steam a second time (double reheat). New materials were developed over the years to permit the use of steam at ever-increasing temperature and pressure.

While other concepts and technologies were, and are now, being developed to produce electricity, the dominant method utilized in the world today remains steam power plants.[4]

At the Pearl Street Station, the steam driving the engines was at a pressure between 60 and 160 pounds per square inch (psi) (0.4-1.1 MegaPascal [MPa]) and at a maximum temperature of approximately 365°F (185°C). For its day, the thermal efficiency of the plant was high. Nevertheless, only about 2.5 percent of the heat energy in the coal was converted to electricity. The rest of the energy was discarded. It took a little over 10 pounds (4.5 kg) of coal at Pearl Street to produce one kilowatthour (kWh) of electricity[5].

The trend over the past century in power plants was to progressively exploit higher levels of steam pressure and steam temperature. These trends are shown in the charts in *Figures 1 and 2.* The combined effect of these trends, coupled with improvements made in the efficiency of power plant machinery, resulted in a corresponding increase in the thermal efficiency of power plants shown in *Figure 3.*

Improvements in efficiency over the years meant a dramatic reduction in fuel consumption for each kilowatthour generated. Since the cost of fuel is a dominant factor in determining the cost of electricity, the price of electricity continued to decline.[6] In the mid-1950s the most efficient units produced a kilowatthour of electricity from about 0.65 pound (0.3 kg) of coal, an enormous improvement since the Pearl Street Station. To continue the trend of improved performance, it was clear that new, bold steps had to be taken.

CROSSING THE CRITICAL PRESSURE BARRIER

Prior to construction of Philo 6, all steam-electric power plants operated with steam well under the “critical” pressure of 3,208 psi abs. (22.1 MPa abs.). For practical engineering reasons, boilers must operate with a comfortable pressure margin below (or above) the critical pressure.

When water above critical pressure is heated, the water

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[4] Today, such plants, fueled by coal, gas, oil and nuclear fuel account for almost 75 percent of the installed generating capacity and produce over 90 percent of the electric energy in the United States. Worldwide, steam-electric power plants generate over 80 percent of the electric energy. *Source: U.S. Energy Information Administration*

[5] In the early decades of the electric utility industry, a common way of expressing the efficiency of a power plant was the weight of coal it took to produce one kWh of electricity. Later, it was more common to express efficiency as a “heat rate,” the amount of heat energy (British thermal units [Btu]) required to produce one kWh. Alternatively, thermal efficiency was expressed as a percentage of the heat energy that was converted to electricity. Ten pounds of coal per kWh is equivalent to a heat rate of approximately 130,000 Btu per kWh (38 kJ per kW-sec) or a thermal efficiency of approximately 2.5 percent.

[6] That trend was reversed in the early 1970s when the energy crisis resulted in much higher fuel and other costs.

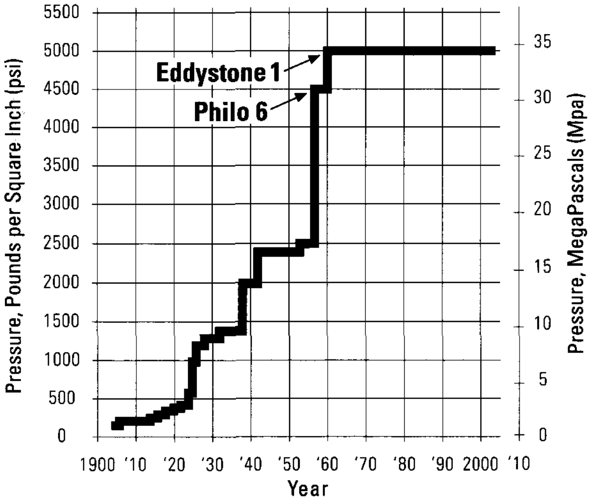

Figure 1: MAXIMUM STEAM PRESSURE IN STEAM-ELECTRIC POWER PLANTS. *For the first two decades of the 20th century, engineers gradually increased the maximum steam pressure in new power plant designs. From the mid 1920s to the mid 1950s several bold steps were taken, notably in 1925, 1939 and 1941. Further progress was halted during, and for several years following, World War II. The next, and very bold step was taken in 1957 when Philo 6 broke the critical pressure barrier of 3,208 psi (22.1 MPa). Eddystone Unit 1 followed that in 1960 to the highest pressure level ever utilized in a steam power plant. For economic reasons that level was lowered in subsequent units and, to date, has not been surpassed.*

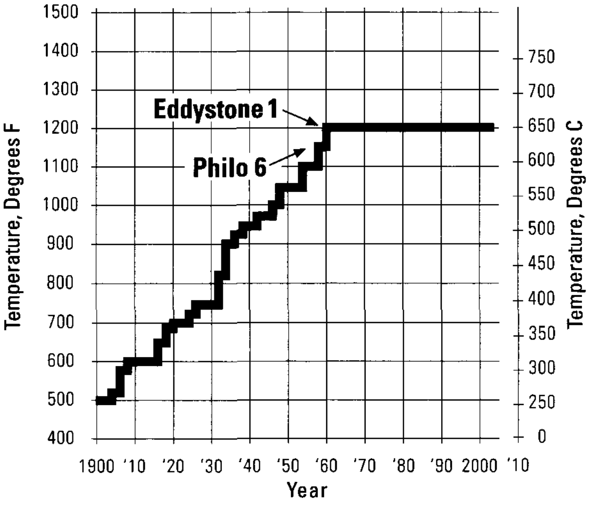

Figure 2: MAXIMUM STEAM TEMPERATURE IN STEAM-ELECTRIC POWER PLANTS. *For most of the first six decades of the 20th century, the maximum steam temperature in power plant designs gradually increased. The trend was approximately 12F° (6.7C°) per year. After the step taken by Philo 6 in 1957, Eddystone 1 followed in 1960 to the highest design temperature level ever utilized in a steam power plant. For economic reasons that level was lowered in subsequent units and, to date, has not been surpassed.*

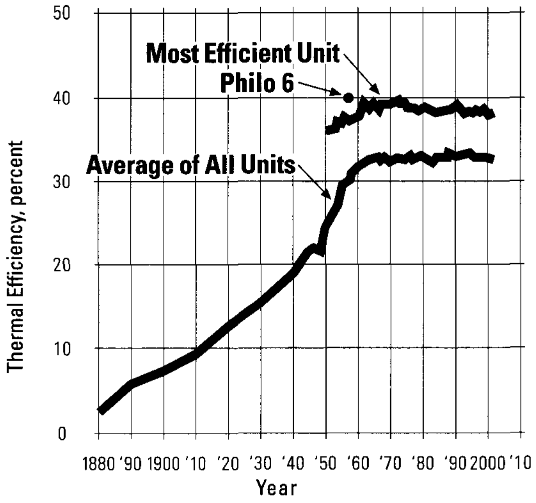

Figure 3: THERMAL EFFICIENCY OF FOSSIL-FUELED STEAM-ELECTRIC POWER PLANTS. *Thermal efficiency represents the percentage of beat energy in the fuel that the power plant converts into electricity. This chart shows the trend in the average annual thermal efficiency of all fossil-fueled (coal, gas or oil) steam-electric units in the United States. (In 2000 there were over 1,800 such units.) It also shows, for the past five decades, the performance of the most efficient units in the U.S. (For comparison, the efficiency of Philo 6 at full load is shown.) From the beginning of the industry through the early 1960s, efficiency improved as plant designers exploited progressively higher steam temperature and pressure. When those increases stopped and leveled off, further improvements in efficiency also leveled off.*

does not "boil" in the usual sense before it becomes steam. The transition to steam occurs above the "critical" temperature of 705°F (374°C).

Under these conditions, water and steam have the same density, and the two are indistinguishable from each other. Stream at a pressure and temperature above the "critical" values is referred to as "supercritical" steam.

The impetus to break the critical pressure barrier sprang from the desire to continue the trend of improving the efficiency of power plants and reducing their construction and operating costs. It was generally accepted that the peak in thermal plant performance had been achieved with the then-current technology. A completely new approach would be required it any new breakthroughs to a higher level of operating economy were to be made.

Philip Sporn[8], then president of AEP, commented in 1953, "The more the problem was studied by the engineers of Babcock & Wilcox Co., General Electric Co. and American

Carnot was a seminal thinker

One of the fundamental physical principles guiding power plant development was first expressed by a brilliant french physicist and military engineer, Nicotas Leonard Sadi Carnot (1795-1832). When Carnot was only 28 years old he published a text "Reflection on the more power of Heat"[7]. These reflections, which form the foundation of the science and engineering of thermodynamics reveal that the efficiency of a heat engine depends on the temperatures between which it works Higher efficiency is achieved with a higher temperature difference — that is, the difference between the temperature at which heat is supplied and, for steam power plants, typically the ambient temperature Carnot wrote, "It is easy to see the advantages possessed by high pressure machines over those of lower pressure. The steam produced under a higher pressure is found at a higher temperature. Exporting this principle the technology at steam power plants advanced over the years by utilizing higher and higher steam pressure and temperature. Such advancement required the development of new economical materials at sufficient strength at high temperature.

ASME launched study of steam properties

An interesting offshoot of the design at philo 6 relates to the fact that its engineers were basing their calculations regarding the behavior of supercritical steam on outdated and extrapolated measurements of steam properties. In 1921, ASME had formed a Research Committee on the Properties of Steam. At that time, data on steam properties extended to 600 psi (4.1 MPa) but was based on extrapolation of research done at only one-third of that pressure. Subsequent work led to the publication, in 1936, of steam properties that extended to supercritical pressures but even that work was based on extrapolation of data. When Philo 6 was designed, those 1936 property tables (Keenan & Keyes) were still in use. Because of the need to bring the research up-to-date, ASME later extended its work well into the supercritical region, but it was not until 1963 that is preliminary results were published. That was a decade after the design of Philo 6 began. In the mid 1950s John A. Tillinghast, P.E., AEP's staff mechanical engineer on Philo 6, served as secretary of ASME's steam properties research committee and later served as its chairman for many years.

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[7] Dr. Robert H. Thurston, the first president of ASME, translated Carnot's original French text into English in 1880. The full title in English, is "Reflections on the Motive Power of Fire and on Machines Fitted to Develop that Power."

[8] Philip Sporn (1896-1978), an electrical engineer by training, may have been the second most honored man in the history of the electric utility industry, the first being Thomas Edison. Sporn wrote 10 books, received 13 honorary degrees, served on numerous government committees and was elected a Fellow at seven engineering sociaties, including the National Academy of Engineering and the ASME. When Philips Sporn retired in 1961, the trade publication *Electrical World* editorialized. "This is trualy a unique man. There is no aspect of the electric power business — management, finance, engineering, operations, load building, public relations, politics or other — that has eluded his sharp, deep understanding or his often acid comments...Perhaps his greatest achievements lie in the engineering field. Uncounted cases of his pushing forward the boundaries of mechanical, civil and electrical and system engineering come readily to mind, all traceable to his devotion to the goal of staying ahead of the field."

Electric Power, the more clear it became that any significant progress now that would, at the same time open up the way for further progress in the years ahead, lay in breaking away from present conventional design limits and limitations in pressures, temperatures, and reheat... ."

To cross the critical pressure barrier presented many engineering challenges. Research work by B&W, GE and others showed that the challenges could be overcome.

Some of the key engineering challenges were:

Steam generator design: In subcritical pressure units, the boiler typically utilizes a steam drum to separate the steam from the water. In a supercritical unit, there is no "boiling" and hence no need for a steam drum. Further, with no density difference between water and steam, natural circulation of water through the boiler's tubes is not possible. An entirely new "steam generator" design concept had to be developed in which water became steam as it passed through the "transition zone" of the steam generator. In fact, the term "boiler" was no longer appropriate since the water did not "boil."

Water purity: In subcritical units, impurities in the water feeding the boiler are separated when the water boils and are not carried through with the steam. They remain in the boiler and can be removed. In a supercritical steam generator, there is no such separation, and water has to be more than a thousand times purer than was previously required. Achieving this higher purity required new methods of chemical treatment, including filtering and demineralizing the water. Before Philo 6 could be built, many design problems with no existing solutions had to be worked out through test programs.

Steam turbine design: The extreme pressure and temperature steam that the turbine had to handle and control presented many mechanical engineering challenges. Use of austenitic or high alloy steel and "cooling" of the turbine rotors with lower temperature steam were solutions that were explored in designing the Philo 6 steam turbine.

Other components: Pumps had to be developed to pump water into the steam generator at a pressure of 5,500 psi (37.9 MPa), and materials had to be developed for the piping to withstand these extreme conditions of pressure and temperature. At 1,150°F (621°C), pipes carrying the steam glow red hot, and the strength of the material becomes significantly lower, requiring very thick pipes. In addition, an entirely new concept of how to control the operation of the unit had to be developed to assure reliable, automatic control.

PHILO 6 BECAME A PROTOTYPE

Engineering studies by AEP in the early 1950s indicated that large supercritical units were the most practicable approach to advancing the economical generation of electric energy. But, because there were far too many unknowns to embark on large-scale production units, a prototype was chosen to prove the soundness of the basic concepts of supercritical pressure, higher steam temperatures, double reheat and, particularly, the adequate control of water chemistry. Engineering judgment suggested that the prototype should be the minimum size to yield valid operating experience. If justified, the technology could be scaled up, with reasonable size extrapolation, to future production units.

The unit finally chosen for the prototype was rated at 120,000 kW, somewhat larger than the average size, but about half the capacity of the largest units for its time. The steam would be at 4,500 psi (31 MPa) and 1,150°F (621°C) with two stages of reheat, the first to 1,050°F (566°C) and the second to 1,000°F (538°C). Water would be supplied to the steam generator at 5,500 psi (37.9 MPa) at a flow rate of 675,000 pounds per hour (85 Kg per sec.).

The diagram in *Figure 4* depicting the heat cycle or heat balance of Philo 6 shows the flow path of water and steam throughout the power cycle.

To minimize cost, the new unit was located at AEP's existing Philo Plant, which had an experienced operating and maintenance staff. Additionally, the site was centrally located in AEP's service area. The prototype would be the sixth unit at the plant.

AEP's Philo Plant was on the Muskingum River at Philo, Ohio, about 55 miles [88 km] east of Columbus, the state capital. The village of Philo was incorporated in 1833 and named for Philo Buckingham, a local landowner. The town's founder had built a dam across the river to create a head of water of about 12 feet (3.9 M) to run a sawmill and flourmill. In 1922 AEP decided to build a steam-electric power plant at that site and utilize the head of water to permit gravity flow of cooling water through the steam condensers instead of the usual practice of pumping the cooling water. That was successful, except in the summer months when some pumping was required.

It is fitting that the Philo Plant was selected in 1953 as the site for the new supercritical unit as Philo 1 was also a pioneer in its own time. Philo 1, a 40,000 kW unit commissioned in 1924, was among the first steam-electric units in the world to utilize the reheat concept. Philo 1 was dismantled in 1954 to make room for Philo 6. The higher efficiency of the new unit, with three times the capacity of Philo 1, enabled it to fit into just about the same space and require approximately the same quantity of cooling water from the river as the older unit! A general cross-section drawing and plan of the main floor of Philo 6 are shown in *Figures 5 and 6.*

B&W DESIGNS A STEAM GENERATOR THAT CAN TAKE THE HEAT

The Babcock &Wilcox Company[9] began the business of building steam boilers in 1867. The company built the four boilers for Edison's Pearl Street Station in 1882. In the succeeding years, B&W built boilers that produced steam at progressively increasing pressure and temperature. B&W boilers created many of the steps shown in *Figures 1 and 2.* The size (steaming capability) of the boilers also was increasing, as was their reliability, so that by the 1940s, engineers were building power plants with generating units consisting essentially of only one boiler and one turbine per unit. Previously, a bank of several boilers was needed to supply steam to a turbine.

By the early 1950s, when enough knowledge was acquired to permit a very significant jump in steam pressure, W.H. Rowand[10], B&W's vice president of engineering, observed, "A steam generator for pressures above the critical presents many considerations in design, metallurgy, fabrication and operation. The solution to some of these has come from the experience and research of the past. Solutions to others have come from active, continuing present-day research. Undoubtedly, some problems will be encountered which will have to be solved after Philo 6 is put into operation."

An artist's rendering of the Philo 6 steam generator is shown in *Figure 7.* A scale model of the steam generator is on display in the Power Machinery Hall at the Smithsonian Institution's National Museum of American History in Washington, D.C.

Extra attention was given to keeping the components of the steam generator as rust free as possible during its manufacture and assembly to achieve optimum cycle cleanliness and water conditions. After assembly it was decided to flush and chemically clean as much of the cycle as was safe and practical. B&W engineers, referring to the Philo 6 steam generator after one year of operation, reported that, "No real difficulties were encountered during the initial startup and the few troubles which have shown up subsequently are minor compared with those which ordinarily might be expected in a major engineering development of this type."

GE PUSHES DEVELOPMENT OF STEAM TURBINES

General Electric Company was formed in 1892 and in 1897 purchased the rights to a multiple-stage turbine from Charles Curtis. Under the guidance of GE's vice president E.W. Rice, Jr., and engineers William LeRoy Emmet and Oscar Junggren, a 5,000 kW steam turbine was built and installed in 1903 at the Fisk Street Station in Chicago[11]. In the succeeding years, GE

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[9] In 1886, the company's co-founder, George Babcock, became the sixth president of ASME.

[10] Will H. Rowand, (1908-2001) was a Life Fellow of ASME.

[11] The Fisk Street turbine was replaced in 1909 with a larger machine. The original, which was among the first steam turbines made by GE, was returned to the factory and put on display. In 1975 it was designated a Historic Mechanical Engineering Landmark by ASME.

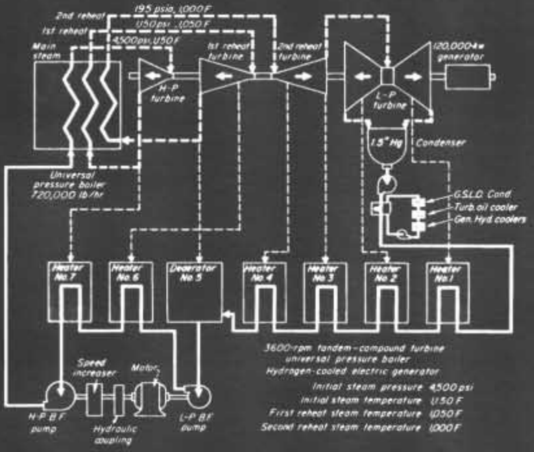


Figure 4: The heat cycle diagram shows the flow of water and steam throughout Philo 6. The values of pressure and temperature are shown for the unit operating at full capacity. Feed-water heaters (boxes shown in the middle of the diagram) preheat the water entering the steam generator, utilizing steam extracted from the turbine.

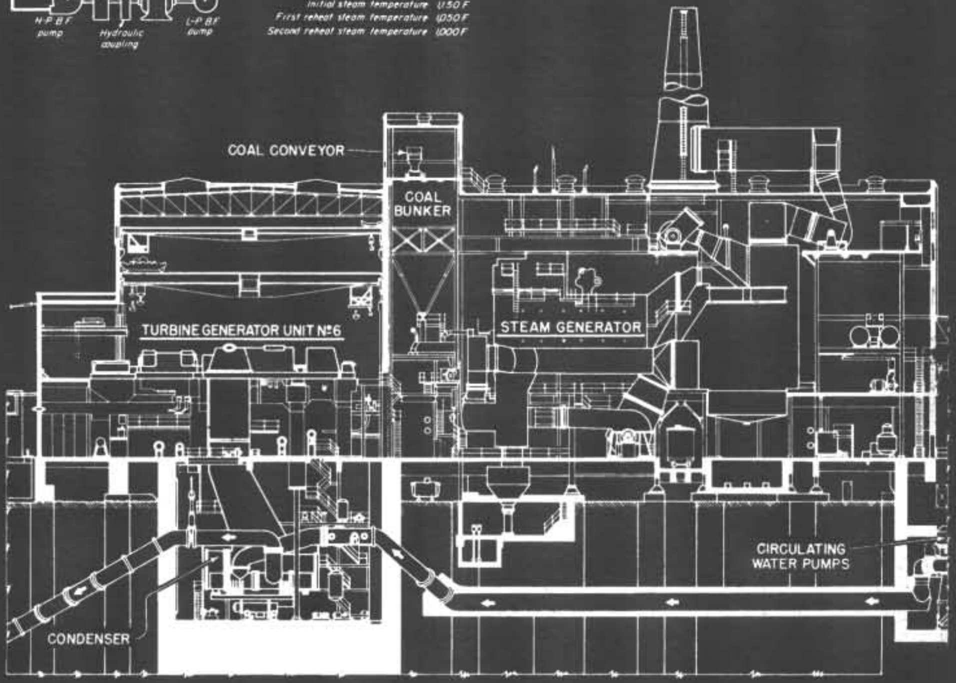


Figure 5: The general cross-section of Philo 6 shows the relative location of the steam generator, the turbine generator and other major components. The overall length of the turbine generator is approximately 93 feet (28 M)

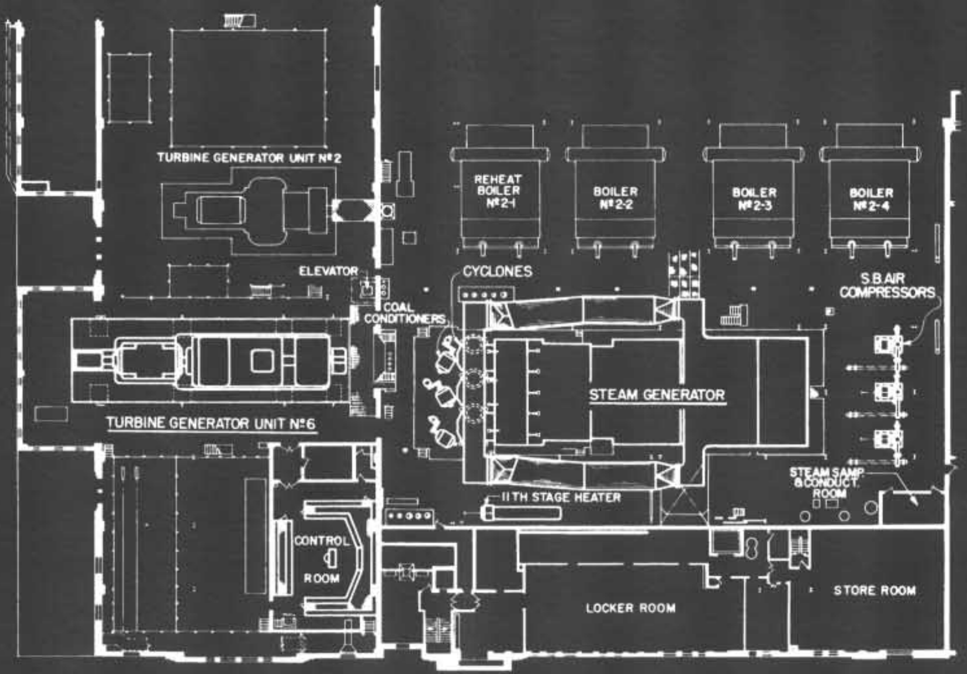


Figure 6: Plan view of Philo 6 main floor. Note the adjacent Unit 2, a 1925 vintage machine. Unit 6, with a capability of 120,000 kW, was built in just about the space formerly occupied by Unit 1, a 40,000 kW unit.

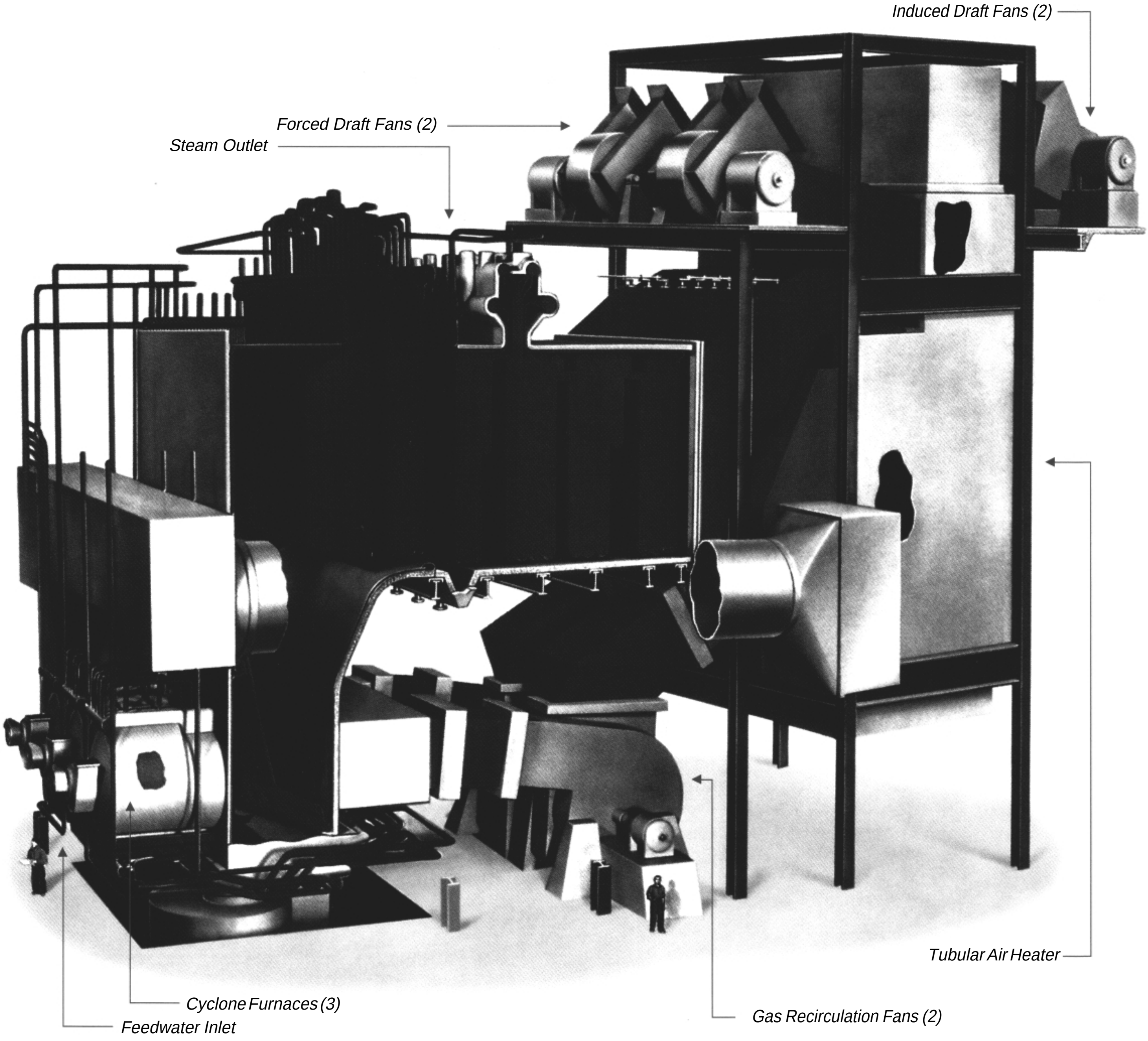


Figure 7: The rendering above is the Philo 6 steam generator, manufactured by Babcock & Wilcox. This unit carried the manufacturer's designation UP (Universal Pressure) 1, the first one made. To get a sense of its size, note the 6-foot-tall (183 cm) people standing near the bottom center and bottom left Coal was burned in three cyclone furnaces (lower left). Water was pumped into the steam generator and was heated as it flowed through the tubes in one continuous path. At full capacity, it took 2¼ minutes for the fluid to pass from the inlet to the outlet. The fluid left as supercritical steam and was piped to the steam turbine. The two forced draft fans (top center) provided combustion air. The two gas fans (bot tom center) recirculated gas to lower the temperature in parts of the steam generator to prevent ash fouling and overheating. The large vertical structure on the right is the tubular air heater which preheated the combustion air. The induced draft fans (upper right) removed the combustion gases and sent them to the stack

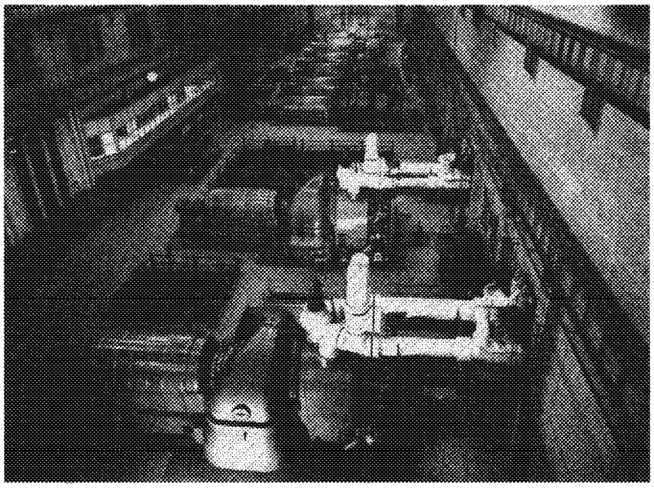
designed steam turbines for progressively increasing steam pressure temperature. GE and turbines made possible many of the steps shown in *Figures 1 and 2.* The size (kW capability) of the turbines was also increasing, as was their reliability. In 1941, for example, the team of AEP, B&W and GE made singnificant advances in steam conditions to 2,300 psi (15,9 MPa) and 950° F (510°C with reheat to 900°F (482°C when AEP's 76,000 kW Twin Branch 3 was commissioned.

In the early 1950s, Charles W. Elston, GE's manager of turbine engineering, observed, "From the turbine designer's point of view, the advance to the Philo 6 steam conditions represents a step twice as large as any previously taken because the [almost] doubling of throttle pressure is combined with a 50F° (28 C°) increase in initial temperature."

He continued, "New engineering knowledge from actual operating experience with Philo 6 turbine will enable the industry to continue, with confidence and good business risk, its development of more economical electric power production through higher initial steam conditions."

The Philo Plant turbine room prior to the installation of Unit 6 is shown in *Figure 8.* The turbine-generator for Philo 6 is shown in *Figures 9 and 10.*

After the turbine was in service for a year, R. Sheppard, GE's manager of turbine product engineering, wrote," . . . Operating data and experience clearly justifies the conclusion that the performance of this turbine fully meets the expectations of the designers."



OTHER ENGINEERING CHALLENGES REMAINED

When Philo 6 was designed, Ted Frankenberg, AEP's chief mechanical engineer, felt that in addition to the steam genera-for and turbine, three features of a supercritical unit presented singnificant challenges. They were:

- *the chemical control system to maintain purity of the water*
- *the feed pumps that deliver water to the steam generator*
- *the stem bypass systems (needed to by-pass steam around certain portions of the steam generator and around the turbine when starting up shutting down the unit)*

Initial operation revealed problems with each of these features, particularly with the feed pumps, though solutions, or ways to alleviate the problems, were found.

An unanticipated problem developed when copper, from the feed water heaters and steam condenser, was carried by the water and steam and deposited in the steam generator and on parts of the turbine. A procedure for dealing with this issue was developed through chemical cleaning, modified operating procedures and the decision, on future supercritical pressure units, to minimize the use of copper material in contact with the water.

Note: A full presentation of the engineering and other details o the unit is beyond the scope of this brochure. Those interested in such detail may refer to the technical papers listed in the bibliography.

Figure 8: This photo of the Philo Plant's turbine room was taken in 1950. In the foreground is Unit 1, a 40.000 kW unit (commissioned in 1924) which operated with steam at 600 psi, (4.1 MPa) and 725°F (385°C) with reheat to the initial temperature. Next is Unit 2 (1925), a twin of Unit 1. That was followed (1929) by Unit 3 at 165,000 kW , a triple-compound unit (with three generators), and the same steam conditions as the first two units. Next came Unit 4 (1941) and Unit 5 (1942). Each was a 90,000 kW cross-compound unit (two generators per unit). Each used steam at 1.300 psi (9 MPa) and 950°F (510°C) and were non-reheat. In 1954, Unit 1 was dismantled to make room for Unit 6. All of the turbine-generators at the Philo Plant were manufactured by GE.

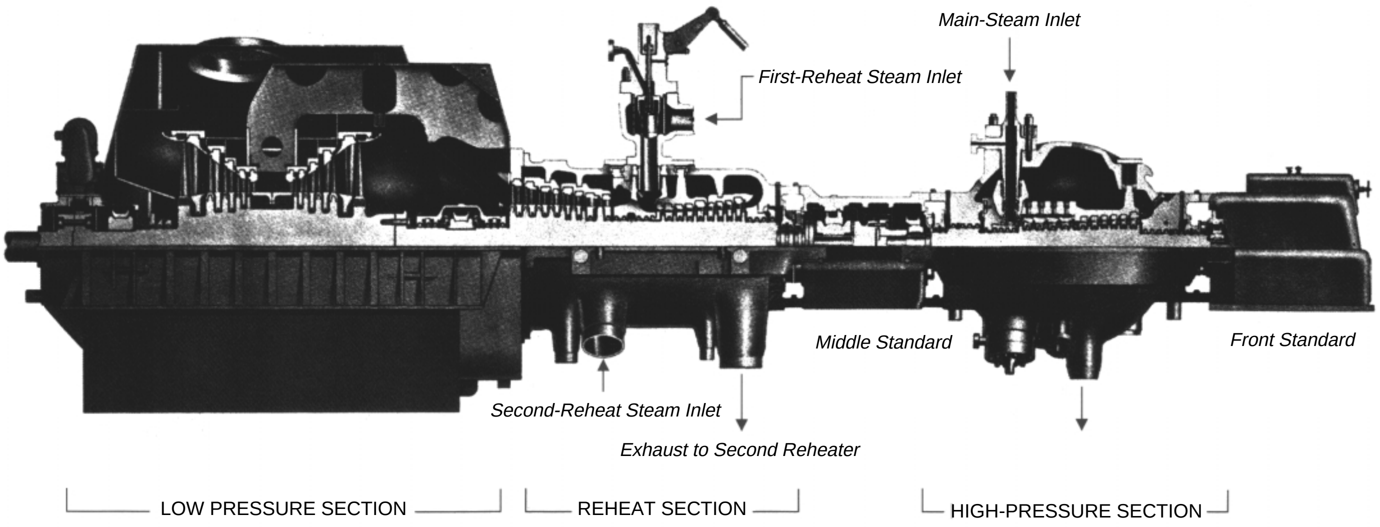


Figure 9: The Philo 6 single-shaft turbine–generator consists of three separate turbine casings. On the right end is the front standard which houses the controls and oil pumps. Next is the high–pressure (h-p) turbine which receives the supercritical steam from the stem generator. The steam flows through the h–p machine toward the front. The steam then is sent back to the steam generator for its first reheating. The reheated steam enters the reheat turbine, flows toward the front, and is then sent back to steam generator for its second reheating. The reheated steam reenters the reheat turbine but this time flows toward the back and where it enters a crossover pipe and is sent to the double-flow low pressure (l-p) turbine. After passing through the l–p turbine, the steam exhausts at sub–atmospheric pressure to the steam condenser (not shown) where it is condensed back to water. The turbine shaft rotates at 3,600 rpm and is directly coupled to the electric generator (not shown) on the left, adjacent to the l–p turbine.

Figure 10: Photo of Philo 6 turbine room taken after Unit 6 (foreground) was installed in the location previously occupied by Unit 1.

FROM THEORY TO PRACTICE — PHILO 6 AND BEYOND

AN ANALYSIS OF PHILO'S ROLE IN HISTORY

After a year of operation, Philip Sporn wrote, "The design, construction and initial operation of Philo 6 has been success–ful in breaking through the supercritical pressure barrier, thus continuing the improvement in efficiency of steam–electric power generation.

"It has given enough operating experience to act as a check on every basic design conclusion or to indicate means of cor–rection of inadequacies or error." Further, he concluded, "Philo 6 also provides a sound foundation for the design and con–struction of new more efficient generating units of the largest size required by large system economics."

Even before Philo began operation, enough confidence was gained by AEP, B&W and GE to begin the design of two 450,000 kW supercritical, double- reheat units. Both of these units began operation in 1960. In the following three decades, AEP built 16 more supercritical units in progressively increasing size, up to 1,300,000 kW.

During its commercial life, Philo 6 operated for 103,110 hours and delivered more than 9.1 billion kWh, net. Philo 6 was retired in 1979, some 22 years after it began operation. Although Philo 6 was a reliable and efficient unit at that time, it was retired along with the remaining older units at the Philo Plant because it was uneconomical to upgrade the plant to comply with the requirements of the Clean Air Act.

The cost of building Philo 6 in 1957 was $20.3 million or approximately $170 per kW. This cost was about 20 percent more than the estimated cost of a conventional subcritical unit of the same capability. It was expected that the experience gained with Philo 6 and the economy of scale would make it possible to build larger supercritical units in the future at substantially lower cost. That belief was indeed borne out. By the mid-1960s large supercritical units with capability of over 600,000 kW were being built for close to $100 per kW.

At the same time that AEP was designing its 450,000 kW units, Philadelphia Electric Co., with its equipment suppliers, began the design of the 325,000 kW Eddystone Unit 1, which extended steam pressure and temperature to still higher values. To date, those levels have not been exceeded. Eddystone 1 began operation in 1960 and continues in operation today. Eddystone 1 also was designated a Historic Mechanical Engineering Landmark by ASME in 2003.

The upward trend in steam temperature and pressure has leveled since 196O. This has resulted in a leveling of the average efficiency of steam power plants. In fact, efficiency regressed slightly as new plants were built, or existing plants were modified, with sophisticated air quality systems to remove pollutants from flue gases and with cooling towers to minimize thermal discharge to rivers and lakes. Since the 1970s those factors, along with other economic considerations, have resulted in significant increases in the capital cost of building steam power plants.

All large coal-fueled steam units constructed by AEP and most large steam units built by others since Philo 6 have incorporated one or more of the technologies introduced by this pioneering unit. At the dawn of the 21st century, worldwide, there were more than 525 supercritical generating units in service, ranging in size from 200,000 kW to 1,300,000 kW. These subsequent units, steadily advancing in reliability as the technology matured, have contributed greatly to the advancement of the world's economy, which is closely dependent on electric power production. Today's large steam-electric generating units supply electricity in vast quantities at lower cost than otherwise possible, as a result of utilizing engineering concepts pioneered by Philo 6.

And what of the future? While a plateau of steam pressure and temperature has existed for the past four decades, further efficiency increases in power production have already come about through the use of units that combine combustion (gas) turbines with steam turbines. Although Sadi Carnot could not have possibly envisioned such machines, he had a keen insight when, in 1824 he speculated, "...perhaps in *low* temperature, steam may be more convenient. We might conceive even the possibility of making the same heat act successively upon air and steam. It would only be necessary that the air should have, after its use, an elevated temperature, and instead of throwing it out immediately into the atmosphere, to make it envelop a steam boiler, as if it issued directly from a furnace."

Carnot foresaw what we today call 'combined cycles' that operate at thermal efficiencies of 50 percent or more with the promise of further improvements on the horizon. That is a far cry from the 2.5 percent of Edison's Pearl Street Station and a big improvement over the 40 percent of the most efficient steam plants today. ◆

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B&W: *Steve Bryk, P.E.*

GE: *Mark Friday*

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This commemorative brochure was written by R.I. (Dick) Pawliger, P.E., based on material listed in the bibliography and in the book *And There Was Light — The Story of AEP — Its First 85 Years* by W.W. Corbitt. Other sources were private communications and interviews of those pioneering people who engineered, designed, operated and maintained Philo 6. Dick is a Life Fellow of ASME and spent his 40-year engineering career with AEP.

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THE HISTORY AND HERITAGE PROGRAM OF ASME INTERNATIONAL

The History and Heritage Landmarks Program of ASME International (the American Society of Mechanical Engineers) began in 1971. To implement and achieve its goals,ASME formed a History and Heritage Committee initially composed of mechanical engineers, historians of technology and the curator (now emeritus) of mechanical engineering at the Smithsonian Institution, Washington, D.C. The History and Heritage Committee provides a public service by examining, noting, recording and acknowledging mechanical engineering achievements of particular significance. This Committee is part of ASME's Council on Public Affairs and Board on Public Information. For further information, please contact *Public Information at ASME International, Three Park Avenue, New York, NY 10016-5990, Phone: l-212-591-7740.*

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Since the History and Heritage Program began in 1971, 227 landmarks have been designated as historic mechanical engineering landmarks, heritage collections or heritage sites. Each represents a progressive step in the evolution of mechanical engineering and its significance to society in general. Site designations note an event or development of clear historic importance to mechanical engineers. Collections mark the contributions of a number of objects with special significance to the historical development of mechanical engineering.

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HISTORIC MECHANICAL ENGINEERING LANDMARK

PHILO 6 GENERATING UNIT

1957

PHILO 6, NEAR ZANESVILLE, OHIO — REPRESENTED HERE BY A PORTION OF ITS STEAM-TURBINE ROTOR -WAS THE WORLD'S FIRST UTILITY GENERATING UNIT USING STEAM AT THE SUPERCRITICAL PRESSURE OF 4,500 PSI, ALMOST TWICE THAT OF PREVIOUS UNITS AND AT 1,150°F. THIS AND OTHER INNOVATIONS RESULTED IN A THERMAL EFFICIENCY OF 40% — A ONE-THIRD INCREASE OVER ITS CONTEMPORARIES. IT BECAME THE TRAILBLAZER FOR MANY THAT FOLLOWED, ADVANCING THE TECHNOLOGY IN NUMEROUS AREAS INCLUDING STEAM-GENERATOR AND TURBINE DESIGN, METALLURGY, AND FEEDWATER CHEMISTRY. THIS 120,000 KW UNIT WAS A COOPERATIVE DEVELOPMENT OF AMERICAN GAS & ELECTRIC (NOW AMERICAN ELECTRIC POWER), BABCOCK & WILCOX, GENERAL ELECTRIC, AND OTHER COMPANIES.

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS-2003

The plaque presented by ASME International to designate Philo 6 a Historic Mechanical Engineering Landmark — August 7, 2003

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