CHILDS-IRVING HYDROELECTRIC PROJECT,
CHILDS SYSTEM: CHILDS POWERHOUSE
Forest Service Road 708/502
Camp Verde vicinity
Yavapai County
Arizona

HAER NO. AZ-65-EE

HAER
AZ-65-EE

PHOTOGRAPHS

WRITTEN HISTORICAL AND DESCRIPTIVE DATA

FIELD RECORDS

HISTORIC AMERICAN ENGINEERING RECORD
Intermountain Support Office - Denver
National Park Service
P.O. Box 25287
Denver, Colorado 80225-0287

HISTORIC AMERICAN ENGINEERING RECORD

CHILDS-IRVING HYDROELECTRIC PROJECT, CHILDS SYSTEM: CHILDS POWERHOUSE

HAER No. AZ-65-EE

Location:	Childs Station No. 363+72.6. Forest Service Road 708/502, Camp Verde vicinity, Yavapai County, Arizona. USGS Payson Quadrangle, UTM Coordinates: NAD 27 Zone 12 435732.4895E - 3800819.716N.
Dates of Construction:	1908-1909.
Engineer:	Iva Tutt; Francis S. Vielé; Raymond S. Masson.
Present Owner:	Arizona Public Service (improvements), P.O. Box 53933, M.S. 3190, Phoenix, AZ 85072-3933; U.S. Government, U.S.D.A. Forest Service (land).
Present Use:	Hydroelectric power generation (November 2004).
Significance:	The Childs Powerhouse was the focal point of operations for the Fossil Creek hydroelectric endeavor, eclipsed somewhat by the completion of the Irving Powerhouse in 1916. Adjustments over the years to the water delivery system and some equipment at Childs changed very little in its basic arrangements of operation, including original water wheels and generators, between 1909 and 2004.
Historian:	James W. Steely, November 2004.

Project Information:

Between February and November 2004, Arizona Public Service (APS) and SWCA Environmental Consultants documented the hydroelectric complex, under guidance of the Historic American Engineering Record (HAER). Project managers Phil Smithers (APS) and Linda Martin (SWCA) coordinated historian Steely, photographer Jessica Maggio, and draftsman Hanson Todachine to complete the HAER documentation. Archives for the Childs-Irving Hydroelectric Project are at APS in Phoenix, Arizona.

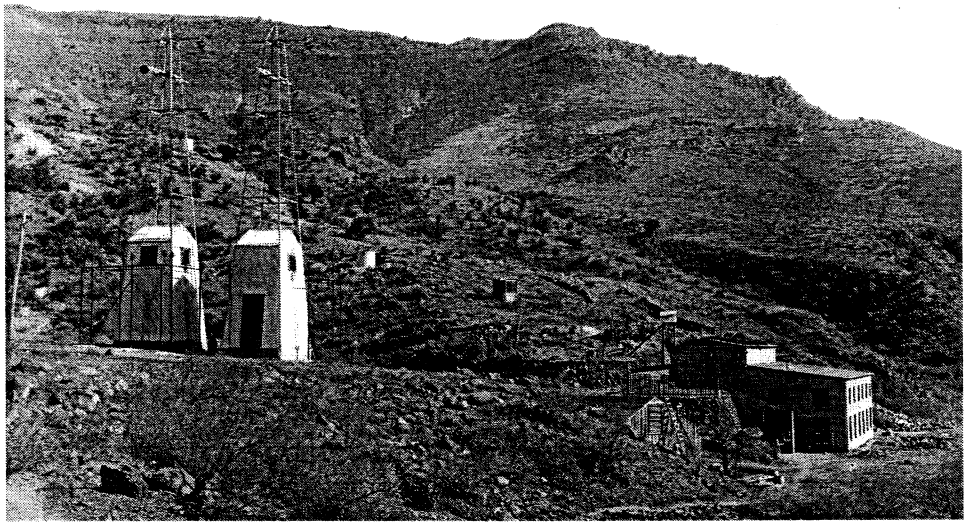
Historic and Engineering Context:

The Childs-Irving Hydroelectric Project encompassed a unique water-pressure/electric-turbine system—according to engineering historians evaluating the historic complex since 1976—that 1) was constructed with great effort in an extremely remote landscape, 2) captured a natural water source and followed dramatic topography, 3) generated electric power in a remarkably simple and efficient manner, and 4) operated continuously for 95 years.

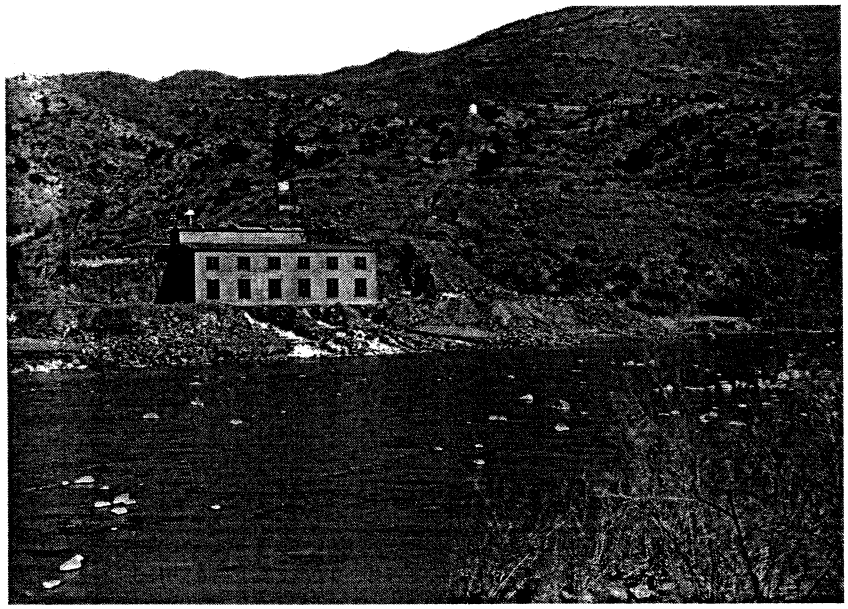
In addition to its individual significance nationwide, the Childs-Irving Hydroelectric Project is a classic part of Arizona history spanning the 20th century: remote low-grade mining operations sought reliable and less-expensive energy; a combination of investors, entrepreneurs and engineers modified a natural resource to supply the energy; cutting-edge technology entered a harsh and remote landscape; an isolated labor force merged those with skills learned far away with local residents, including Native Americans with traditional ties to the land; nearby communities soon offered an additional customer base; farmers and irrigation cooperatives became major consumers for their pumps and agricultural machinery; distant metropolitan areas boomed by tapping the energy source; and finally a conservative operational approach to investment and maintenance retained aging technology within a huge modern power grid for many, many years past a reasonable retirement.

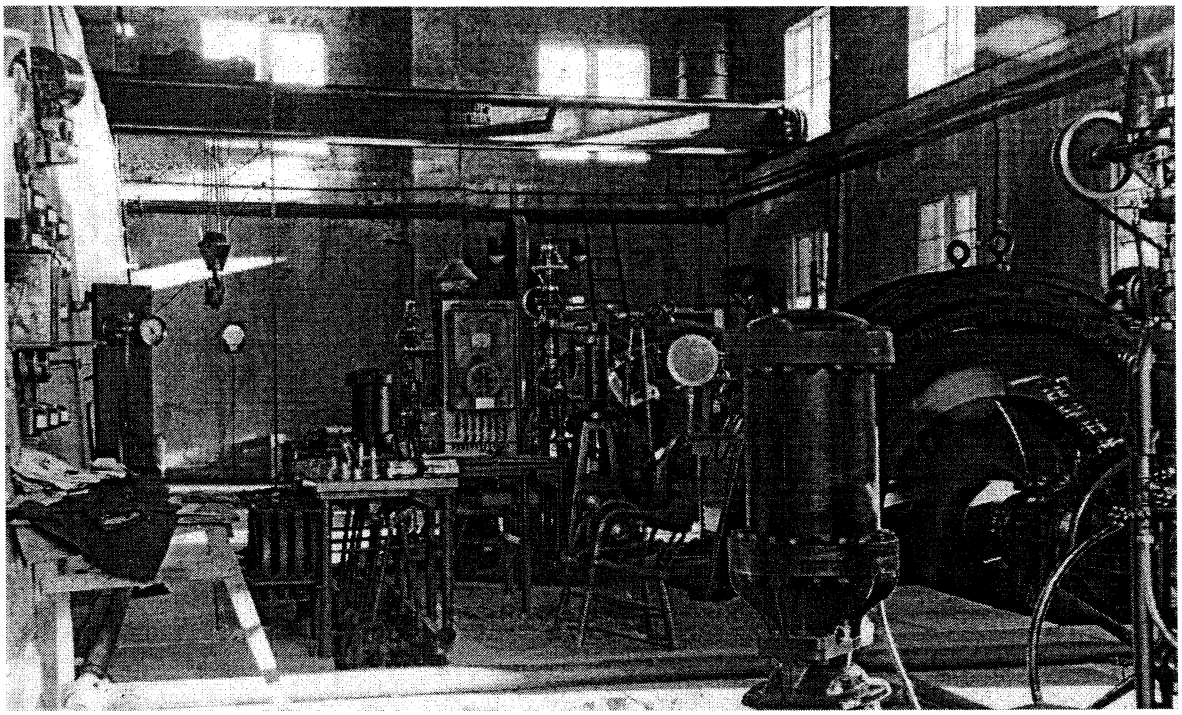
Character Defining Attributes

Component/Feature No.44 on National Register form. The one-story Childs Powerhouse was built of reinforced concrete, on a foundation 30.5 feet wide and 76 feet long, under steel trusses and a corrugated roof (possibly of asbestos-cement sheets). Inside, three Pelton-type impulse water wheels (impeller blades moved under direct water pressure, a high-pressure design as opposed to the low-pressure Irving wheel) built by Abner Doble of San Francisco, each turning at 400 revolutions per minute under 1050 foot head of pressure, delivered up to 3000 horsepower. The water wheels were each direct connected to a General Electric 400 rpm, 3-phase, 2300 volt, 1800 kilowatt alternating-current generator. Water was discharged through three tailraces directly into the Verde River. Since construction, porch awnings were added and windows covered with louvered grills, and all electric switching equipment upgraded. About 1950 the common-wall transformer house (under low-pitched gable roof in historic photos and on historic plans) was demolished and a new structural framework added to carry three transformers. (Effland and Macnider 1991; APS)



Above – APS Photo Library #152. Below – APS Photo Library #150, Childs powerhouse as viewed across the Verde River. Connected Transformer House was "daylighted" about 1950 with removal of outside walls and its separate gabled roof. Note "windmill" towers at left, above, modified to hold more switching equipment, now removed.





Childs Powerhouse interior. APS Photo Library #3. View is looking east with switching panels at left, operator's station in middle, #1 power unit's cutoff-valve head on right and governor on extreme right, #2 power unit's generator and exciter at right middle ground, #3 power unit in background, and overhead crane on tracks above.

Use and Operation *(see also Photos, Maps and Drawings)*

Engineering Context

The use of wheels turning shafts for generating mechanical power is a human-work multiplying innovation dating at least from Greek antiquity. The guidance of natural watercourses to turn wheels and shafts for mechanical power grew to widespread use in Europe during the middle ages. In the early 19th century in the United States, tests of the mechanical efficiency of such water wheels led to vastly improved designs. One British-born engineer—James B. Francis working with water-powered industrial mills on the Merrimack River through Lowell, Massachusetts—combined efficiency studies with French development of the water "turbine." Nineteenth century turbine innovators such as Francis sought to extract the maximum power from the water's "head," or pressure from its drop in elevation, whether from a flowing stream or from a natural or artificial "fall." The turbine they envisioned is "a rotary engine that extracts energy from a fluid flow…usually [with] a casing around the blades that focuses and controls the fluid" (Farlex 2004).

> The main difference between early water turbines and water wheels is a swirl component of the water which passes energy to a spinning rotor. This additional component of motion allowed the turbine to be smaller than a water wheel of the same power. They could process more water by spinning faster and could harness much greater heads. (Schoenau 2004)

The "Francis turbine" developed in Massachusetts in the 1850s utilized 90 percent of the force of water directed to its rotor blades, as opposed to a contemporaneous industry standard of 65 percent or less (Hawke 1988). The Francis design, "the first modern water turbine," is an "inward flow reaction turbine," meaning that penstock-pressured water fills the turbine housing, the wheel turns in reaction (rather than from highly focused "impulse" pressure as with a Pelton wheel; see below), and a low-pressure head of water moves the turbine relatively fast (Farlex 2004). "By the 1870s variants on the Francis turbine became the most widely used hydraulic prime movers in America, at a time when water power was still more important than steam for industrial purposes" (Hawke 1988).

The impulse-type "Pelton wheel" was patented in 1880 by Lester Allan Pelton (1829-1908) in California after watching the characteristics of other water wheels and turbines.

> The Pelton Wheel operates off the inertia of water that impacts on cupped buckets. The Pelton is used wherever there exists a high head of water of at least 50 ft and needs very little flow…. The Pelton is comparatively small for its output and can attain high operating speeds reducing the need for expensive gearing. (Schoenau 2004)

Inventor Pelton further modified the Francis turbine's innovations by sculpting the wheel's blades into "buckets" with two cups each (Alston 2004). "You can approximate that design by cupping your hands upwards, then bringing them together, with the fingernails of one hand

touching the ones of the other" (Stern 2004). Pressurized water, focused by a needle-valve nozzle into a jet at the end of its penstock, strikes the center joint of the two cups. The water first pushes the blade, which turns the wheel; then the water's movement across the semi-hemispherical shape of the cup transfers even more energy from the water and turns the wheel faster.

> That was Pelton's great discovery. In other turbines the jet hit the middle of the [single] cup and the splash of the impacting water wasted energy. In technical terms, the impact there resembled an inelastic collision, whereas in the turbine which Pelton developed, the deflection of the jet resembled an elastic collision....
>
> Through the later 1870s Pelton developed his design, settling in the end on a double cup with a wedge-shaped divider in the middle, splitting the jet–half to the left, half to the right.... In the winters of 1877 and 1878 he tested turbines of different sizes, including a small one for running his landlady's sewing machine....
>
> Pelton then tried to sell his turbines, but met with little success until the spring of 1883, when the Idaho Mining Company of Grass Valley in Yuba County, California, arranged a competition between different designs, before deciding which design it would buy. Pelton's turbine won by reaching an efficiency of 90.2%, whereas the three competing water wheels only attained 76.5%, 69.6% and 60.5%. After that sales grew at a tremendous rate, and in 1888 Pelton with some partners formed in San Francisco the Pelton Water Wheel Company, which expanded production even more. (Stern 2004)

The first large-scale production of electricity for consumer and industrial use also resulted from a burst of innovations and spirited competition in the 1880s in the United States. In 1879 Thomas Edison adapted the direct-current (DC) generator—producing a flow of electricity from the rotary motion of magnets, an 1830s British discovery of Michael Faraday—to the successful power of a vacuum-tube light bulb. The most credited first "hydroelectric" application linking Edison's DC-powered lights to a water-powered system opened in 1882 at two paper mills in Appleton, Wisconsin. The same year a small California system, with a generator and paddle wheel turned by irrigation water in Etiwanda Colony below the San Gabriel Mountains, lit the colony developer's home and an elevated outdoor carbon-arc light (Clucas 2002). Soon Edison offered a number of other inventions powered by DC, including powerful motors that approached the output of steam engines. But Edison's motors, like steam engines, needed to be close to the application of power, since DC voltage drops considerably when wired too far—less than two miles—from the generator (*EPRI Journal* 1979:36). Edison's obsession with DC devices obscured consumer and industrial opportunities possible through centralized generation of electricity distributed over long distances. (*EPRI Journal* 1979; Farlex 2004)

Serbian-born inventor Nicola Tesla, while working briefly for Edison, developed an understanding of alternating current (AC) that could be transmitted long distances by wire or cable without dramatic loss of power. Tesla "realised that...doubling the [AC] voltage would halve the current and reduce losses by three-quarters," that AC could be "transformed" back and

forth from DC, and AC voltage could be stepped up and down for efficient transmission over long distances (Farlex 2004). Tesla patented his system, based on constant-speed AC generators, including transmission and transformers in 1887. He then joined forces with inventor George Westinghouse in proving their AC power-distribution system superior to Edison's DC inventions. Tesla's breakthrough system produced relatively low-voltage AC current from generators, stepped it up to high-voltage AC for distribution through long-distance wires, then transformed it back to lower-voltage AC to power lights and machines a considerable distance from the generator. Further, AC could be converted to low-voltage DC at the job site to power small variable-speed tools such as drills, saws, and tram locomotives.

> With Tesla and his patents, Westinghouse built a power system for a gold mine in Telluride, Colorado, in 1891, with a water driven 100 horsepower (75 kW) generator powering a 100 horsepower (75 kW) motor over a 2.5 mile (4 km) power line. Then in a deal with General Electric, which Edison had been forced to sell, Westinghouse's company went on to construct a power station at the Niagara Falls [, New York], with three 5,000 horsepower Tesla generators supplying electricity to an aluminum smelter at Niagara and the town of Buffalo 22 miles (35 km) away. The Niagara power station commenced operation on April 20 1895. Its opening set the scene for the electric power industry for over a hundred years. (Farlex 2004)

The same year as the Niagara power project's opening, 1895, the City of Sacramento, California, first drew 11,000 volts of AC power from Folsom Powerhouse on the American River 22 miles away. This innovation demonstrated the rapid spread of hydroelectric technology across the United States, and forced New York's Niagara project to share with California several of its "firsts" in the transmission of AC voltage a long distance for municipal and industrial consumption. The Folsom operation also wedded the experience of water systems related to mining operations—heretofore moving American River water through ditch and flume systems only to assist in mineral excavation and washing—and the growing trend of assisting mining with water-powered mechanical and electrical devices. The Folsom Powerhouse focused a water head of 50 feet into four "McCormick" (probably the manufacturer of Francis reaction turbines) dual turbines of 1260 horsepower each, direct-connected to four 750-kW General Electric generators, producing 3000 kW. (*EPRI Journal* 1979; Bell 2004)

By the end of the 19th century, mining and associated industrial processes embraced electric-powered machinery for a number of reasons. Mines generally developed around deposits in remote areas; electricity transmitted by wires from single generating plants ("central stations") greatly reduced the costs of constantly shipping exhaustible fuel to the mine site. Equipment for excavating mines and extracting minerals had to be compact and portable; by 1900 air-powered mining tools proved most efficient, charged by pumps in turn powered by electrical generators. Air pumps also supplied oxygen to workers deep in mineshaft labyrinths. Once workers opened mineshafts wide enough and deep enough, elevators and trams could be built into mines for hauling workers in and raw materials out; electric vehicles powered by unobtrusive wires brought no dependent fuel or choking combustion into the mine. Successful and large-scale mines processed their low-grade ore as much as possible on site to reduce shipping fees;

conveyor belts, tumbling mills, sifters, smelters, and other giant machinery worked most efficiently when powered by electric motors. (Effland and Macnider 1991)

Fossil Creek Water System

The inventions of James Francis and Nicola Tesla, and the early hydroelectric projects of California, were widely published by the late 19th century in the United States, and their successes grew to industrial-scale enterprises. As Arizona and other Western regions opened to settlement and natural resource extraction through railroad connections, government and industrial agents mapped these landscapes thoroughly and noted mineral and water resources necessary to any sustained development. With knowledge of hydroelectric systems already in service in California and east of the Mississippi River, especially those supplying power to mining and industrial operations, anyone with some knowledge of harnessing water power could recognize the potential at Fossil Creek.

Indeed, hydroelectric power arrived elsewhere in Arizona just as the Fossil Creek project investors formulated their plans. "The development of hydroelectric power from Fossil Creek was not the first such project in Arizona," wrote Effland and Macnider (1991:8/4) in their Childs-Irving National Register nomination. "Hydroelectric generation of power in Phoenix began in 1902 with establishment of plants on both the Arizona and Grand canals."

The popular Childs-Irving Hydroelectric Project story that about 1900 Verde River rancher Lew Turner spontaneously envisioned a hydroelectric facility in the Fossil Creek wilderness is quaint. But this creation myth conveniently omits the existing context of hydroelectric successes in the last decade in neighboring California and nearby Phoenix. The story also only hints at the presence of growing mining operations in the Bradshaw Mountains to the west, each with management hungry for cheaper power and therefore exploring every water course in the region for hydroelectric potential. Finally, this simplified origin of the The Arizona Power Company (TAPCO), so quickly assembled in 1902 by Turner plus Long Beach, California, electrical engineer Iva Tutt and others, breezes past another inspiration associated with Niagara and Sacramento: their hydroelectric operations represented a pioneering and essential assembly of financing and technological expertise. TAPCO and its Fossil Creek venture assembled a modern consortium of remote investors, equipment manufacturers, engineering designers, industrial consumers, and political opportunists. (*EPRI Journal* 1979; Effland and Macnider 1991)

> TAPCO [and its Fossil Creek venture] is but one of at least five hydroelectric generating projects that were planned at the turn-of-the-century to provide power for expanding mining operations in the region [of central and northern Arizona].... Of these enterprises, it was only the Fossil Creek project that succeeded.... (Effland and Macnider 1991:8/3)

The success of Fossil Creek is based largely on its geology (the consistent springs) and geography (its natural drop—without high natural waterfalls—of 1575 feet from the springs to the Verde River). The Childs-Irving project achieved an unusually strong static head pressure

through "the high degree of topographic relief that allows for a drop of 1 foot per 1000 feet over a distance of only 11.26 miles," creating a static head of 480 feet at plant "No. 2," Irving, sufficient for one low-pressure generator ideal for powering a Francis turbine. (Effland and Macnider 1991:8/1)

Thus, designers of the Fossil Creek water diversion and distribution system combined proven techniques (dam and flume construction, basic turbine and generator couplings) with new technology (reinforced concrete, steel pipe) in an extremely remote workplace (portable concrete mixers, machinery and prefabricated structures reduced to wagon-sized loads). (Alston 2004)

Power House No. 1 (Childs) Engineering Design

The 1908-1909 "No. 1" Powerhouse embodied TAPCO's initial expectations for a Fossil Creek hydroelectric system. Workers established a construction camp on a natural terrace along the north bank of the Verde River, accessed by the original road from the railhead to the east at Mayer (Alston 2004). The terrace offered two construction opportunities bisected by the drainage of Quail Tank: on its southeastern plain a site for the Powerhouse, and on its northwestern plain room for the housing and maintenance compound necessary for Powerhouse operation. Northeast of the Powerhouse, the flume system diverted water—after generally following Fossil Creek southerly for several miles downstream—abruptly southwest through Ikes Backbone via (present) Tunnel # 7, into the 4698-foot Penstock delivering water to the terrace and the Powerhouse intake.

The one-story Childs Powerhouse was built of reinforced concrete, on a foundation 30.5 feet wide and 76 feet long, under steel trusses and a corrugated roof (possibly of asbestos-cement sheets). The concrete floor secured the steel-pipe Penstock discharge into three 18-inch branch pipes distributing pressurized water to each of the three water wheels inside. Sub-floor concrete tailraces directed dissipated water from the turbines outside, thence into the Verde River. The concrete foundation also anchored the turbine, generator, exciter and other equipment. The cast-concrete powerhouse walls supported the overhead crane used for initial positioning of equipment, as well as removing and installing components and their "bonnets" during maintenance. Since construction of the building, operators added porch awnings along the southwest elevation, placed louvered grills over several windows, and upgraded all electric switching equipment and transformers.

About 1950 the common-wall transformer house (under low-pitched gable roof in historic photos and on historic plans, on the northeast side of the building), with floor a few feet higher than the generating room, was demolished and a new free-standing structural framework added to carry its three transformers (Effland and Macnider 1991; APS). APS removed these walls and roof to create open-air switching and transformer positions for safety and maintenance.

Water Wheels, or Turbines

Inside the Powerhouse generating room, three high-pressure Pelton-type impulse water wheels, with steel bonnets labeled "Abner Doble" of San Francisco, each turned at 400 revolutions per minute under 1050 foot head of pressure, delivering a maximum total of 3000 horsepower.

> Various inventors...contributed to this [Pelton] type of water turbine, and subsequent important contributions to Pelton-wheel technology were made by William A[bner]. Doble, a San Francisco engineer who patented improvements in bucket forms and nozzle designs beginning February 7, 1899. Doble became chief engineer of Pelton's company in 1912, and his patents represent a second stage in the development of Pelton turbines. (ASME 2004)

At the Childs Powerhouse, the turbines were mounted on the Powerhouse floor in evenly spaced positions along a common axis to accept pressurized water from the Penstock terminals under the floor. From each branch pipe terminal, pressurized water entered its needle-valve nozzle focused against its impeller (wheel) and twin-bucket blades to achieve constant speed (400 rpm) to maintain the attached generators' "base loads" (60 Hz). Each Pelton wheel in the Childs Powerhouse was about six feet in diameter, securing 16 buckets around its perimeter. (Alston 2004)

Pressure Governance

Water pressure in the Childs Powerhouse was regulated through adjustment of each nozzle's needle valve, to maintain constant turbine speed (400 rpm), which in turn regulated each generator's speed within a specific range to maintain the "base load" at the "frequency" of 60 cycles or Hertz (Hz). Generally, a hydropower governor "senses changes in speed and adjusts the water flow to the runner [or turbine wheel] to correct any deviation from the desired speed" (CanREN 2004).

The Child's three turbines each employed a Woodward oil-pressure governor, consisting of a cluster of spinning flyballs or flyweights (a development of steam inventor James Watt in 1769), housed in a metal dome atop the governor stand. TAPCO replaced the original Lombard governors in the 1940s after that company closed and spare parts were no longer available (Alston 2004). Gears and a jackshaft from the turbine turned a continuous belt to gears spinning the flyballs' small vertical shaft.

Thus the turbine-powered governor, through changes in the flyballs' centrifugal spin, sensed any change in turbine speed and mechanically moved two shafts between a bell crank to open a valve in the base of the governor. This valve introduced pressurized oil from the adjacent reservoir (standing vertically on the Powerhouse floor adjacent to the governor stand) into a cylinder (actuator) below the floor. The actuator then moved a series of connecting rods to adjust the positions simultaneously of a "cataract" valve, to divert water flow away from the turbine, and

the needle valve in the nozzle aimed at the bottom of each Pelton wheel. As the cataract valve opened, the nozzle valve closed with controlled slow motion to prevent back-pressure buildup in the Penstock. Each governor stand included a safety mechanism in the form of a "dashpot" that served as an anti-racing device that restored the pressurized-oil actuator/cylinder's "distributing valve" to its neutral position once the governor re-established the desired speed. (Alston 2004)

Generator and Exciter

The water wheels were each direct-shaft connected to a generator built by General Electric as an alternating current (AC), 3-phase, 60-cycle dynamo running at 400 rpm. The resulting 60 Hz cycle standard, credited to Nicola Tesla as one of his innovations with the Westinghouse Company in the 1880s, was the common link between consumer lights and machinery powered by Childs-Irving. This enduring U.S. standard applied at Fossil Creek from initial operations also contributed to this system's long life as part of the 60 Hz power grid of North America.

Each generator shaft continued to a direct-connection with the "exciter," a small DC generator that created the magnetic, alternating field in the main AC generator.

> The output voltage of an AC generator is controlled by...the strength of [its] DC field.... The DC field voltage produced by the [main, AC] generator...is applied to the stationary field of an exciter. An exciter is a small DC generator which is used for the purpose of providing DC field current to an AC generator field.... This concept permits the use of a [AC main] generator...with a lower control current capability as the exciter acts, in essence, as an amplifier. (Kilowatt Classroom 2004)

Each of the Childs Powerhouse's generator-exciter combinations supplied 1800 kilowatts at 2300 volts to insulated cable that carried the current to a distribution bus. The bus in turn supplied current to three transformers, each single-phase 3000 kilovolt Ampere (kVA) units that stepped voltage up to 69000 volts (69 kV) to the transmission lines. Historically, TAPCO customers received this current from transformers stepped back down to 2400 volts, then to 120 volts or 240 volts for lighting and machinery. By 2004, from Childs-Irving and other APS transmission through the North American grid, industrial customers typically received their current from transformers as three-phase 480 volts to 13.8 kV, and residential customers received power from transformers stepping current down to 120/240 volts AC. (Alston 2004)

Water Discharge

After release from the Pelton turbines, dispelled water moved through tailraces in the Powerhouse floor southwest a short distance into the Verde River. (Alston 2004)

Childs Powerhouse in Historic Context

Contextual information on other hydroelectric facilities built at the time of Childs-Irving indicates that the Fossil Creek facility's performance stood statistically between many very small

projects of the period and a handful of much larger enterprises. One example of smaller operations was the 850 kW generator in Phoenix at Arizona Falls on the Arizona Canal, installed in 1902. The original Arizona Falls operation ceased in 1950, but was revived in 2004 by the Salt River Project with a 750 kW generator reportedly capable of powering 150 modern homes (Phoenix 2004). One example of a much larger operation was the plant of five generators built into the U.S. Bureau of Reclamation's first major dam, Roosevelt Dam on the Salt River 75 miles west of Phoenix, producing 4500 kW by 1909 during its construction. The Bureau of Reclamation completed Roosevelt Dam in 1911 and thereafter increased its generating capacity to 36000 kW, still (in 2004) contributing much energy to the Phoenix Basin power grid (Green Nature 2004).

By comparison, the Childs-Irving Hydroelectric Project first offered 2700 horsepower (1800 kW) when the three generators at the Childs Powerhouse commenced operation in 1909. This output more than met the needs at the time of the United Verde (UV) Mine at Jerome, which initially contracted for 1600 horsepower (1220 kW) to energize its first new electrical mining machinery. Completion of the Irving Powerhouse in 1916 added 2100 horsepower (1600 kW) to the Fossil Creek system, meeting additional mining customer demand during World War I. But this addition also maximized the full potential of the Fossil Creek overall plant, and TAPCO soon added a steam-powered plant at Clarkdale—tied into the existing grid but closer to several mining customers including UV at Jerome—with more than 3500 kW output by itself. (Effland and Macnider 1991)

The sale of power from TAPCO's combined Fossil Creek and Clarkdale system to customers in the Phoenix Basin throughout the 1920s indicates that about 7000 kW was a substantial output for the region. TAPCO's capacity survived on these urban sales as its large mining customers dramatically scaled back their production after World War I. And Phoenix found a source of electric power to fuel its accelerating population growth even as Roosevelt Dam sputtered for a decade far below its hydroelectric capacity because of an extended drought throughout its surface watershed.

Standardization of the North American electrical power grid by about 1930 (*EPRI Journal* 1979), and commensurate upgrades of the Childs-Irving Hydroelectric Project, ensured that the remote wilderness-spring-fed 60 Hz technology contributed to an ever-expanding national matrix well into the 21st century. Incredibly, the original Childs-Irving water wheels, generators, and much associated equipment, including the water delivery system itself, still functioned in 2004 through excellent maintenance and relatively minor upgrades (Alston 2004). Installation in 2004 of the newest technology at Arizona Falls in Phoenix, achieving 100 kW less output than its 1902 installation, also confirmed that the Fossil Creek system recognized and achieved its greatest capacity from its initial design and equipment, beginning 95 years earlier.

Bibliography

Alston, Elmer
2004 Personal conversations with James W. Steely. Alston was a 21-year APS veteran and 20-year operator at Childs and Irving Powerhouses. 22 October, 15 November 2004.

American Society of Mechanical Engineers (ASME)
2004 "North Star Mining Museum, Pelton Waterwheel Collection c. 1880." Electronic document: http://www.asme.org/history/roster/H157.html. Accessed 29 November 2004.

Arizona Public Service (APS) Archives
Historic photograph collection. Historic drawings collection. Historic documents collection. Available through appointment at: APS, P.O. Box 53933, M.S. 3190, Phoenix, Arizona 85072-3933, 602-371-7689.

Bell, Daniel
2004 "The Folsom Powerhouse." California State Parks Web site. Electronic document: Accessed 8 November 2004.

CanREN
2004 "Hydroelectric Energy." Natural Resources Canada Web site. Electronic document: http://www.canren.gc.ca/tech_appl/index.asp?CaID=4&PgID=1154#governors. Accessed 10 November 2004.

Clucas, Donald L.
2002 *Light Over the Mountain : A History of the Rancho Cucamonga Area.* California Family House Publishers. Upland, California.

Effland, Richard W., Jr., and Barbara S. Macnider
1991 *Childs-Irving Hydroelectric Facilities.* National Register of Historic Places Registration Form. U.S. Department of the Interior, National Park Service. Washington, D.C.

EPRI Journal
1979 "Creating the Electric Age." Electric Power Research Institute. Palo Alto California. March 1979.

Farlex
2004 "Water Turbine" and "Electric Power." Articles in *TheFreeDictionary.com.* Electronic document: http://encyclopedia.thefreedictionary.com. Accessed 5 November 2004.

Green Nature

2004 "A History of Hydroelectricity in the United States." Electronic document: http://greennature.com/article302.html. Accessed 12 November 2004.

Gulliver, John S., and Roger E.A. Arndt
1991 *Hydropower Engineering Handbook.* McGraw-Hill, Inc. New York.

Hawke, David Freeman
1988 *Nuts and Bolts of the Past, A History of American Technology, 1776-1860.* Harper & Row. New York.

Hay, Duncan
1991 *Hydroelectric Development in the United States, 1880-1940, Bibliography, Volume II.* Edison Electric Institute. Washington, D.C.

Kilowatt Classroom
2004 "Generator Field Control." Electronic document: http://www.kilowattclassroom.com/Generators/GenReg1.pdf. Accessed 9 November 2004.

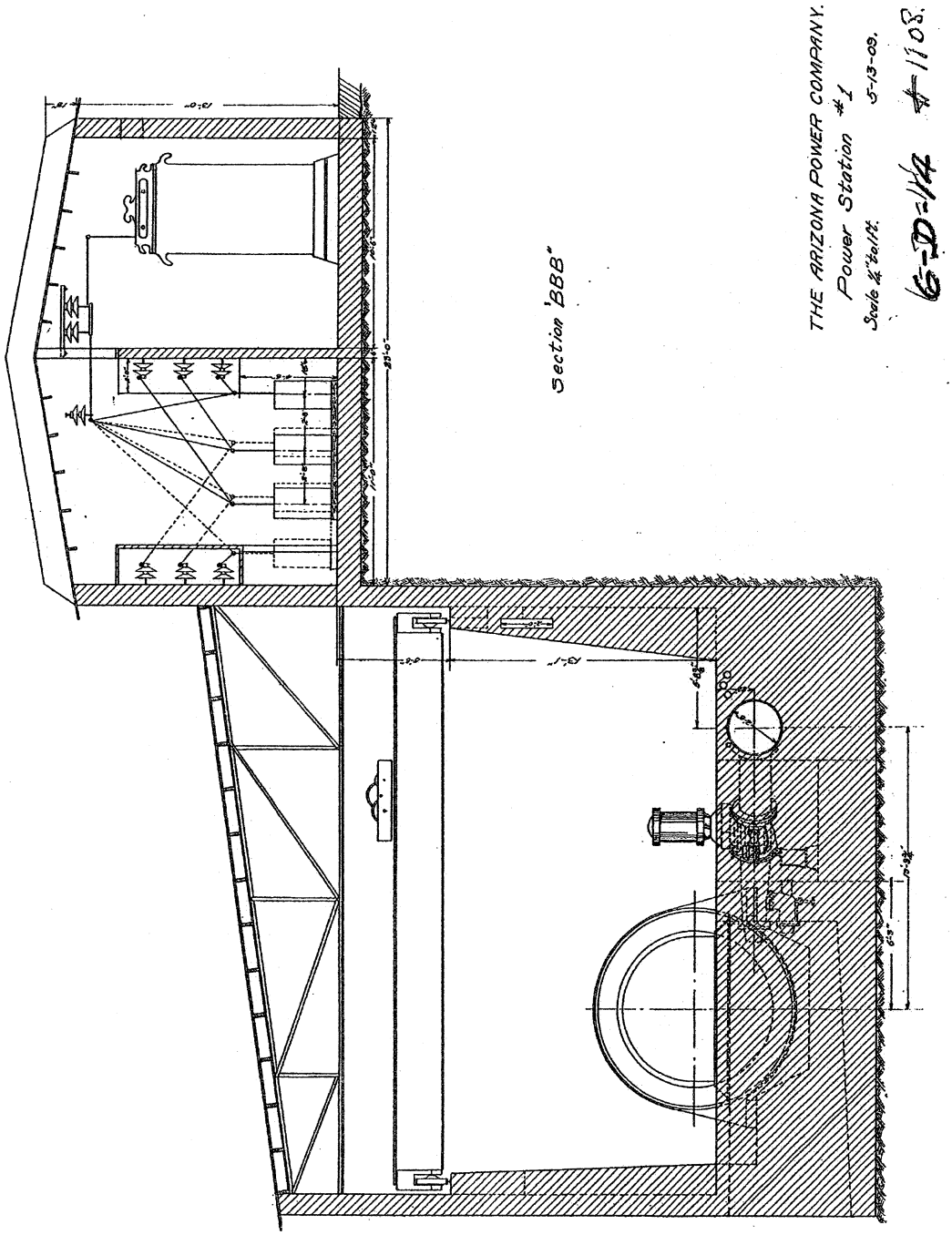
Phoenix, City of
2004 "History Comes Alive at Arizona Falls." Electronic document: http://www.ci.phoenix.az.us/NEWSREL/azfalls.html. Accessed 12 November 2004.

Schoenau, William
2004 "Water Wheel / Turbine." Article on Web page of Plasma-Material Interaction Group. Electronic document: http://starfire.ne.uiuc.edu/~ne201/1996/schoenau/wheel~1.html. Accessed 5 November 2004.

Stern, David P.
2004 "Planetary Gravity-Assist and the Pelton Turbine." Electronic Document: http://www-istp.gsfc.nasa.gov/stargaze/Spelton.htm. Accessed 29 November 2004.

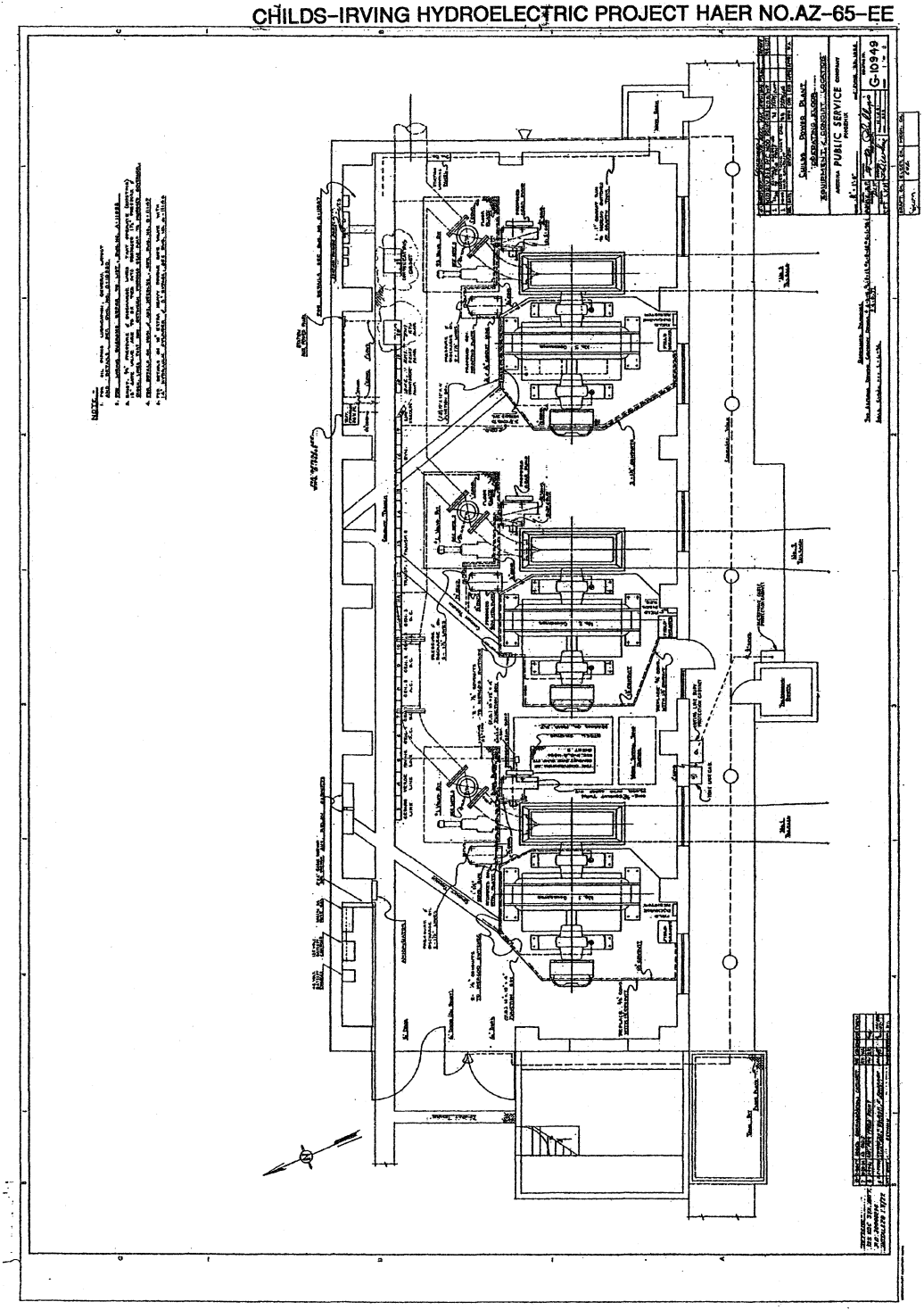
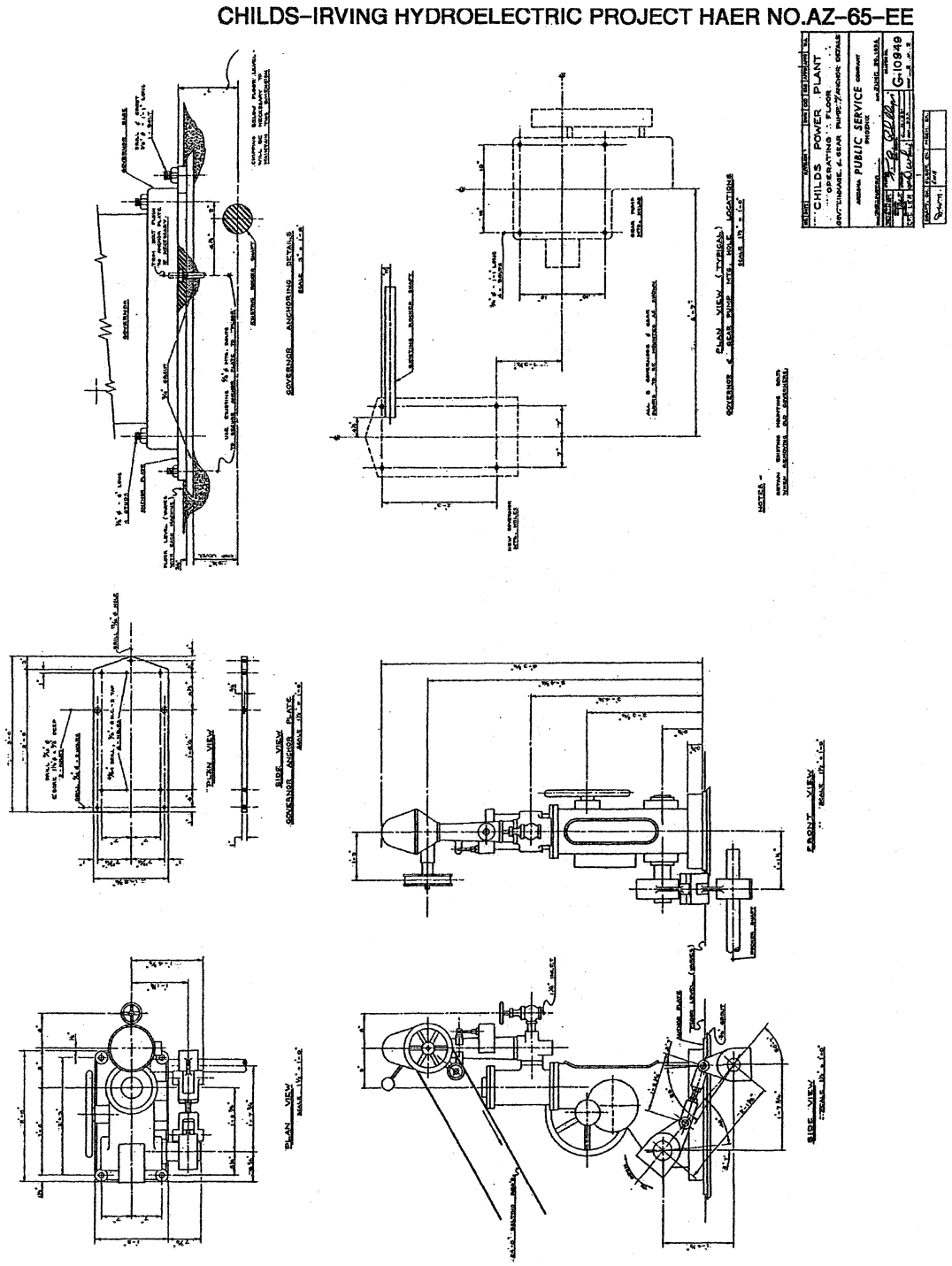
Drawing "Power Station # 1" 1909:

CHILDS–IRVING HYDROELECTRIC PROJECT HAER NO.AZ–65–EE



Drawing "Childs Power Plant Operating Floor Equipment and Conduit Location" 1956:

CHILDS-IRVING HYDROELECTRIC PROJECT HAER NO.AZ-65-EE



Drawing "Childs Power Plant Operating Floor Gov. Linkage and Gear Pump w/ Anchor Details" 1956: