Westinghouse ENGINEER

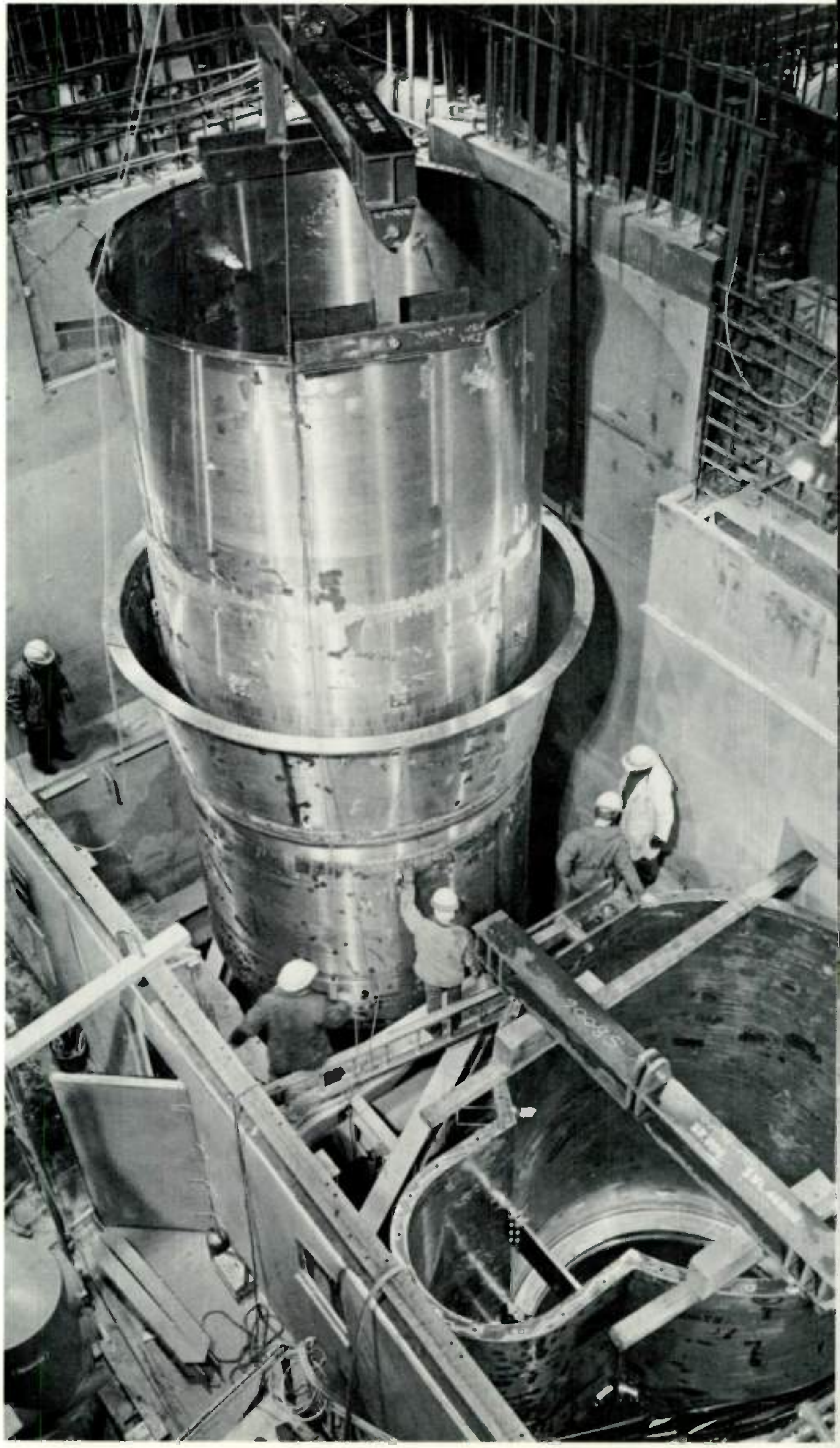
April 1974

FFTF Guard Vessels Installed

Three sets of guard vessels for the primary sodium pumps and intermediate heat exchangers have been installed in the Fast Flux Test Facility (FFTF) at the Hanford Engineering Development Laboratory. The vessels are located in a concrete cell beneath the reactor operating floor. They will contain the sodium coolant in the unlikely event of leakage from the three primary sodium loops.

The first pump guard vessel to be installed is shown in the photograph. It weighs about 23 tons and measures about 14 feet wide by 25½ feet long.

The FFTF will house a sodium-cooled nuclear reactor, test loops, and safety systems when completed. Experience gained in constructing and operating it will help develop the technologies needed for commercial liquid-metal-cooled breeder reactors. Westinghouse Hanford Company manages the Hanford Engineering Development Laboratory for the U. S. Atomic Energy Commission.



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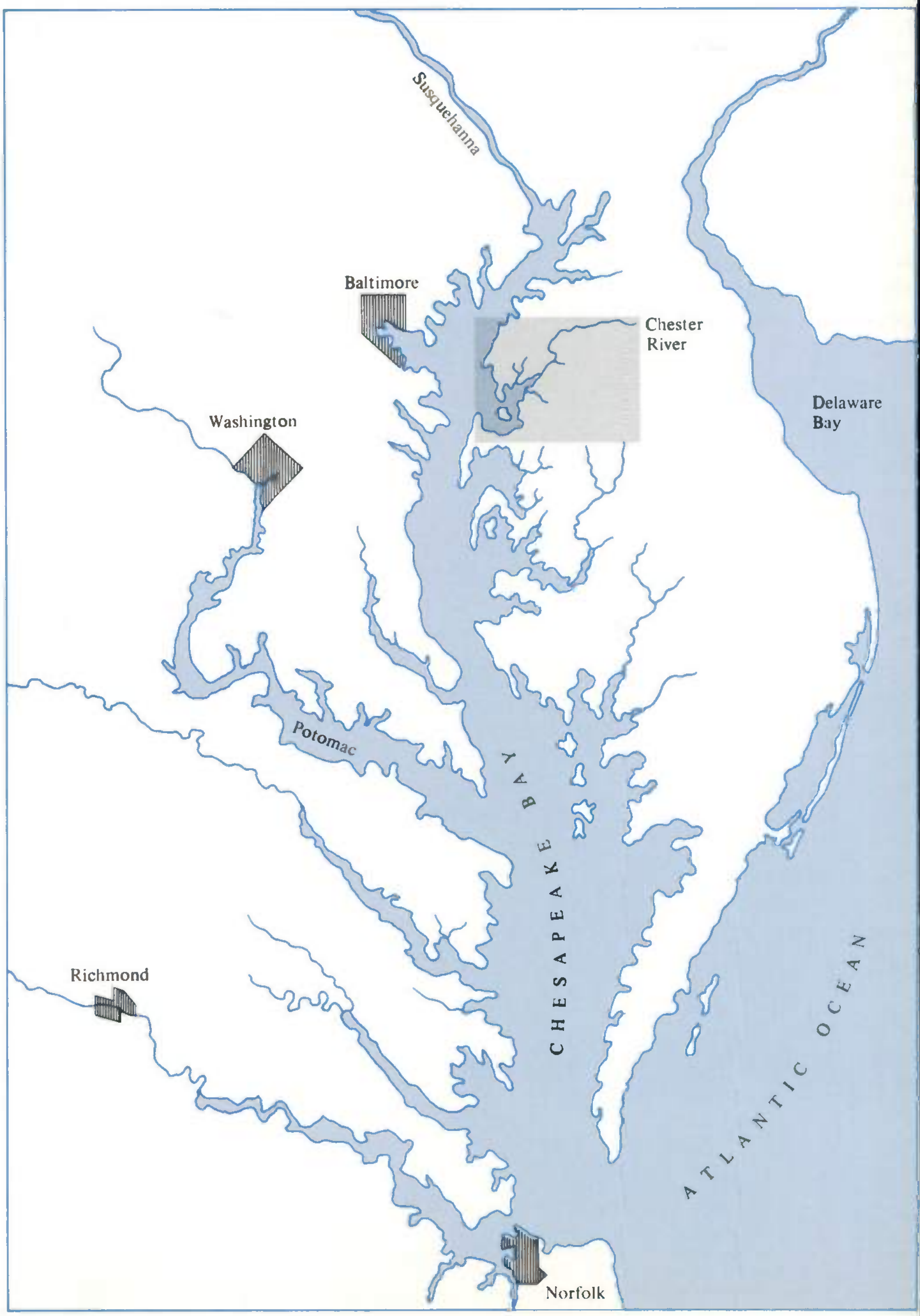
Front Cover: The Chester River Environmental Study, reported in this month's issue, was undertaken to develop information that could be applied to environmental issues and resource management problems of Chesapeake Bay. To represent the Bay region, artist Tom Ruddy chose the skipjack, the sailing vessel used by the oystermen.

Results of the Chester River Environmental Study

The Chester River Study, briefly described in this article, was a year-long cooperative effort (November 1971 to November 1972) of Maryland's Department of Natural Resources and Westinghouse Ocean Research Laboratory. Its goal was the development of information that could be applied to environmental issues and resources management problems. A major discovery was that the flow of pollutants is from the Chesapeake Bay into the Eastern Shore rivers—an indication that the Susquehanna River and Baltimore harbor are probably the main sources of chlorinated-hydrocarbon and PCB pollution. The interdisciplinary study provided interesting new information on the ecological effects of shellfish exposure to pollutants. Of major importance to the Chesapeake Bay fishing industry, it was found that shellfish and finfish from the Chester River are presently safe for human consumption. Some recommendations that resulted from the study are summarized in the article.*

Skipjacks, sailing vessels for the oystermen of Chesapeake Bay, are shown tied up at Kent Island on the Chester River. Shellfish are a major factor in the local economy.



1—Chart of the Chesapeake Bay region shows the location of the Chester River.

A major environmental concern that helped instigate the Chester River Study is the class of chemical compounds called chlorinated hydrocarbons. One major subclass consists of the chlorinated organic compounds used as agricultural pesticides, such as DDT, chlordane, and aldrin. Another subclass contains the polychlorinated biphenyls (PCB's) used in chemical preparations for industrial applications, such as electrical insulating fluids, hydraulic fluids, and heat exchanger fluids, or used as additives to plastics, inks, paints, and sealants. All of these chlorinated compounds are environmental problems because they resist chemical and biological breakdown.

Of specific concern to the state of Maryland is the massive mortalities of soft-shelled clams in recent years in the Chesapeake Bay. State biologists have not been able to explain these die-offs because most of the environmental parameters measured at the time of the mortalities seem to be well within the tolerance levels of the clam. Therefore, scientists hope that more broad-based environmental studies can provide additional information on the effect of environmental pollutants. One question is whether the interaction of two classes of pollutants such as trace metals and chlorinated hydrocarbons could make them more harmful even at low concentrations. Considerable research needs to be done in this area, particularly in carefully controlled laboratory experiments. Thus, trace metals are a second area of concern. More information is needed to determine what quantities might be deleterious to the environment and its living resources.

Shoreline erosion is a third major environmental concern because it destroys valuable land and damages submerged river terraces that are the major harvesting areas for shellfish.

Selection of a Study Area

The Chester River was chosen for the environmental study because it is typical of Eastern Shore river drainages (Fig. 1). Limiting the study to a single river system (most of which lies within the state of Maryland) permitted a more detailed study with available personnel and research facilities than would have been possible for a larger area. The Chester River has extensive commercial fishing—oysters, soft-shelled clams, blue crabs, and finfish. The watershed is used primarily for agricultural purposes, so the area was considered representative of a minimally perturbed environment as far as land modification and the presence of nonagricultural type pollutants were concerned. However, if the opening of the second span of the Chesapeake Bay bridge has its anticipated effect on population growth, that expansion will modify the physical and biological characteristics of the river system. Thus, while the Chester River Study was undertaken to assess the seriousness of present environmental problems, its findings can also provide a reference point for measuring future changes in the river system.

Study Approach and Techniques

A multidisciplinary approach to environmental problems is needed because of the multiplicity of possible paths of pollutants through the environment. Data measurements from all applicable parameters must be assembled on a common time base to permit meaningful analysis. Laboratory analyses of contaminated organisms are required to determine just what levels of contamination constitute a health hazard, either to the organisms or to humans.

For the three major problem areas, five major discipline areas were chosen for study; the interrelationships between them are shown in Table 1.

Table 1—Organizational Matrix of the Chester River Study

	Disciplines				
Environmental Problems and Resources Management Issues	Chemistry	Biology	Geology	Meteorology	Hydrology
Chlorinated Hydrocarbons	X	X	X		X
Trace Metals	X	X	X		X
Shoreline Erosion			X	X	X

The Chester River Study required the collection, storage, and analysis of such parameters as wind speed and direction, tide, currents, and various physical and chemical observations regarding temperature, conductivity, dissolved oxygen, and pH. The development of the various analytical data required two sampling programs: routine field sampling involved the gathering of biological specimens for laboratory analysis, geological samples of shoreline areas, and samples of river-bottom and suspended sediments at multiple depths throughout the river system; the other program was continuous recording of certain parameters in the Chester River, such as current, tide, and temperature. The instruments and systems for continuous recording included ODESSA (Oceanographic Data Environmental Science Services Administrations) buoy systems supplied by NOAA (National Oceanic and Atmospheric Administration); self-recording current meters; Westinghouse meteorological stations; tide gauges and regional meteorological stations, both operated by NOAA; and stream-flow gauges maintained by U.S. Geological Survey.

The locations of instrument stations and repetitive sampling stations are shown in Fig. 2. Hydrological measurements and geological samples were also taken at other locations. Hydrological measurements included longitudinal and transverse transects of the lower river using portable measuring instruments; geological sampling consisted of collection of shoreline and river floor sediments. A complete description of the data sources would be lengthy, but a brief summary is provided in Table 2.

Study Results—Chlorinated Hydrocarbons

Because of the low water solubility of chlorinated hydrocarbons, these compounds initially adsorb on fine particulate matter suspended in water, such as silts and clays. As the compounds work their way up through the food chain, they tend to concentrate in the fatty tissues of the higher organisms. Some behavioral abnormalities and other deleterious effects are known to

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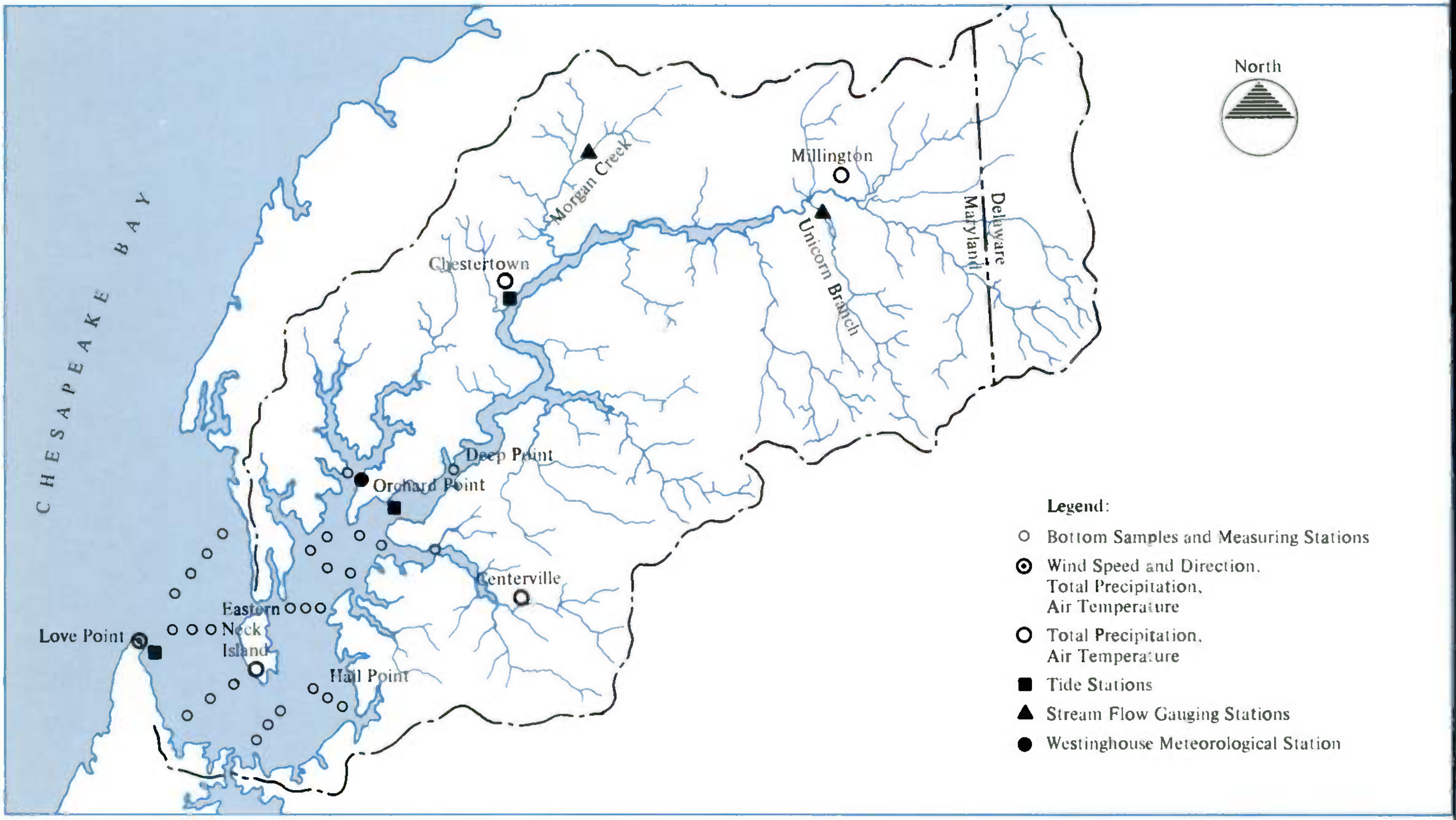
**Acknowledgement:*
The editor acknowledges the work of W. D. Clarke, L. C. Murdock, and H. D. Palmer, Westinghouse Ocean Research Laboratory, editors of *The Chester River Study Reports*, which provided the source material for this article.



result. For example, accumulation of chlorinated hydrocarbons affects the calcium metabolism of the California Brown Pelican, producing thinner eggshells and therefore a higher incidence of egg breakage in the nest. Moreover, the egg yolk also accumulates chlorinated hydrocarbons, impairing the viability of the developing embryo. A logical concern of the Chesapeake Bay fishing industry is the effect that these compounds might have on shellfish.

Three kinds of chlorinated hydrocarbons were found regularly in sediments and biota of the Chester River: PCB's (almost exclusively Aroclor 1242), the pesticide DDT and its breakdown derivatives DDE and DDD, and the pesticide chlordane. The average values for these compounds and their ranges are tabulated in Table 3. Those composite values were derived from all the data collected during the study and include the variability due to seasonal fluctuations, distributional differences resulting from sample location, and species sampled. The table is useful in giving an overall view of chlorinated hydrocarbon levels in the biota and sediments of the Chester River system.

Food is generally considered unfit for regular human consumption if DDT or PCB concentrations exceed 5000 parts per billion by wet weight. The contamination levels found in Chester River organisms, as indicated in Table 3, fall well below that level.

A similar limit for chlordane has not been established because chlordane contamination has not been found to be a widespread problem. However, an "alert level" of 30 ppb for chlordane was established by the U.S. Food and Drug Administration in 1968. At that time there was no evidence of a chlordane problem in Chesapeake Bay. When the Chester River study began to indicate chlordane contamination exceeding 30 ppb, no one could determine why the alert level had been set so low. (The chlordane alert level for fresh vegetables is 300 ppb.) Furthermore, there was the question of whether the original intention had been to make the 30-ppb level merely an alert level or an enforceable closure level for shellfishing.

Extensive analytical work in the Westinghouse Ocean Research Laboratory has shown that chlordane residues are indeed present in shellfish populations and in some instances exceed the 30-ppb alert level. Moreover, the carefully obtained laboratory findings indicated that previous methods of analysis recommended by the FDA's *Pesticide Analytical Manual* do not yield reliable results for levels of chlordane as low as 30 ppb.

All this new information led to a meeting of personnel from the Seafood Section of the U.S. Food and Drug Administration and Maryland's Department of Natural Resources, along with other interested parties. The unequivocal consensus was that no rationale existed for having a chlordane alert level set at 30 ppb for shellfish when the alert level for fresh vegetables is 300 ppb. Furthermore, it was agreed that the effective sensitivity limit for the previously recommended screening procedures for chlordane was on the order of 100 ppb and

(Right)—*Analyses of water samples were often made in the field. Small fast boats permitted scientists to occupy many stations during a day's operation.*

(Lower Right)—*Current speed and direction were important parameters in assessing the exchange of water between Chesapeake Bay and the Chester River. A vertical array of current meters (one partially submerged in this scene) is deployed beneath a telemetering buoy.*

2—(Left) *The major data collection points and sampling station grid used during the study are indicated on this chart of the Chester River.*

hat levels as low as 30 ppb could not be detected reliably. Shortly thereafter, an interim 300-ppb alert level for shellfish was recommended by the FDA pending further studies. On that basis, the chlordane level in oysters and soft-shelled clams taken from the Chester River is low. However, the levels in some finfish analyzed slightly exceeded one-half of the new alert level.

Distribution of Chlorinated Hydrocarbons—The affinity of chlorinated hydrocarbons for fine suspended particulate matter means that their major transport mechanism is suspended sediments, and their distribution in the aquatic environment is linked to the movement of those suspended materials.

Sediment samples from the bottom of the Chester River were analyzed for both geological parameters and chlorinated hydrocarbon levels. Measurement of PCB and pesticide content of the sediment samples as a function of mean grain diameter confirmed earlier findings by other investigators that the smaller the mean grain diameter (hence, the larger the surface area per unit weight), the higher the concentration of chlorinated hydrocarbons present.

While it was concluded (and previously assumed) that suspended clays and silts were the major transport mechanisms for chlorinated hydrocarbons, the *unusual* finding was that the principal transport was from the Bay into the Chester River. Each of the study disciplines contributed some evidence to support this conclusion:

Analysis of the concentrations of PCB's, total DDT, and chlordane revealed that concentration levels diminished in the upstream direction.

The chlordane levels in soft-shelled clams taken from the lower portion of the river were significantly higher than in clams taken from the upper portion.

Fish that do not range far from their established living territories, such as yellow perch and white perch, were found to have considerably higher levels of PCB, DDT, and chlordane in the lower portion of the river than upstream.

Mineralogical analysis of the clay portion of the Chester River sediments disclosed the abundant presence of a clay species (chlorite) that is common to the Bay but is known to be rare within the Chester River watershed.

And finally, current velocity measurements indicated that the prevailing flow pattern in the Chester River is typical of a two-layered system—a net flow of water upstream near the bottom and a net flow of water downstream near the surface. Upstream flow along the bottom provides the mechanism for transporting fine sediments and their adsorbed chlorinated hydrocarbons from the Chesapeake Bay into the lower reaches of the Chester River.

On the basis of the Chester River study as well as work done by others, several likely sources can be identified for the chlorinated hydrocarbon contamination. The quantity of pesticide products sold within the Chester River watershed is small compared with the quantity sold in Baltimore City and County immediately across the Bay, or in the Susquehanna watershed that drains into the northern end of the

Bay. Other studies have shown that at least 80 percent of the water in the upper portion of the Bay comes from the Susquehanna River. Thus, a major contribution to the Chester River is probably from suspended sediments brought by water transport from the upper Chesapeake Bay.

Studies of the distribution of aerosols have generally revealed high concentrations of pesticides in the atmosphere many miles downwind from industrial and urban areas where they were used. Those studies suggest that perhaps 50 percent of the pesticides present in the downwind environment are from atmospheric fallout as fine particulate matter in precipitation. Since more than 95 percent of the winds reaching the Chester River watershed have crossed major industrial and urban centers lying west of Chesapeake Bay, this mechanism may account for a portion of the pesticides found in the Chester River. However, it is presently believed that most of the contamination comes from suspended sediments in the Bay water.

Table 2—Data Source Summary

	Parameter Category	*Data Collection Method*	*Field Storage Form*
Continuously Recorded Data	Measured Tide (3 locations)	In Situ Recording Instrument	Digital Paper
	Meteorological (2 locations)	In Situ Recording Instrument	Digital Serial Magnetic Tape
	ODESSA (7 sensors)	In Situ Recording and Telemetry Instrument	Digital Serial Magnetic Tape
	Current Meters (2 sensors)	In Situ Recording Instrument	Analog Paper (chart)
Daily or Monthly Summaries	Predicted Tide (3 locations)	Computerized Prediction (highs and lows)	Published Values (Baltimore)
	Stream Flow (2 locations)	In Situ Recording Instrument	Digital Paper Tape
	Rainfall (4 locations)	Manual Observation	Field Log
	Air Temperature (4 locations)	Manual Observation	Field Log
Periodic Field Sampling	Physical/Chemical	Portable in Situ Instrument	Field Log
	Current Meter	Portable in Situ Instrument	Field Log
	Geological	Manual and with Field Samplers	Field Log and Sample Retention
	Biological	Plankton Side-Look Sonar Surveys	Sample Retention and Analog Charts
	Biochemical	Field Grab Samples of Water, Sediment, and Biological Specimens	Sample Retention

Table 3—Levels of PCB's and Chlorinated Pesticides Found in Biota and Sediments of the Chester River—Parts Per Billion

	PCB's		*DDT (total)*		*Chlordane*	
Sample	*Average*	*Range*	*Average*	*Range*	*Average*	*Range*
Oysters	55	16—250	43	0—150	36	9—160
Soft-Shelled Clams	58	13—180	21	4.1—130	14	0—38
Fish	185	2—570	134	50—260	74	34—180
Crabs	20	0.4—51	33	18—28	14	3—24
Sediments	87	0—310	16	0—63	5.2	0.2—14

Laboratory Toxicity Studies

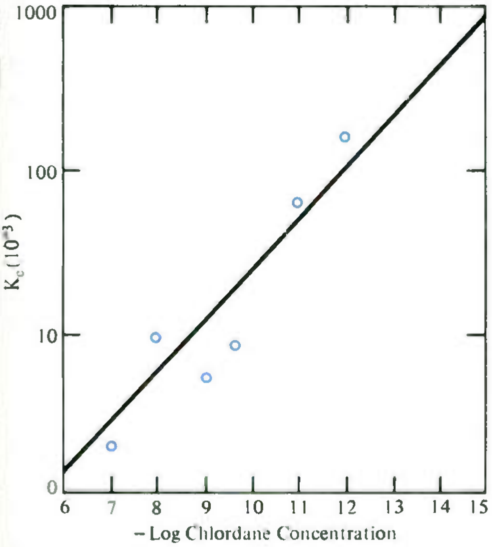
A major part of the Chester River study was devoted to laboratory investigations of the toxic effects of chlorinated hydrocarbons on the oyster and soft-shelled clam with the long-term objective of developing data that would be useful for resource management. Although complete attainment of that long-term objective was not within the scope of the Chester River Study, much useful information was gained.

Chlordane was initially selected for laboratory investigation because it had been detected in shellfish for the first time at levels that approached or exceeded the original alert level of 30 ppb. Soft-shelled clams concentrated chlordane at levels varying from 400 to 1000 times the concentrations they were exposed to during the experiments; oysters accumulated greater amounts, reaching body-tissue levels up to 10,000 times the exposure concentration. However, after high-level exposures, both clams and oysters purged themselves of the accumulated chlordane when removed from the high-exposure environment.

The higher exposure concentrations of chlordane produced morphological abnormalities that are interesting because of the similarity they bear to abnormalities previously observed in soft-shelled clams and oysters subjected to stresses, such as extremes of temperature or salinity in their natural environment. Clams had swollen siphons and blistered surface tissues. Oysters in the highest chlordane exposure concentrations had smaller meats and less developed reproductive organs than oysters held in lower concentrations. If these abnormalities are specifically related to chlordane toxicity, they may become evident at even lower chlordane concentrations when organisms are stressed as they are in nature.

None of these morphological abnormalities were observed in long-term experiments where very low concentrations (1, 10, and 100 parts per trillion) were used. The lowest experimental exposure concentration (1 ppt) produced approximately one-tenth higher body tissue accumulation levels than the levels observed in oysters collected from the Chester River.

Examination of new shell growth with a scanning electron microscope showed that oysters receiving even the lowest chlordane exposures were affected. Altered shell growth is a matter of concern because, even if body tissue accumulation levels in shellfish stocks are considered safe for human consumption, it has not been established in most instances whether these levels are harmless to the food stocks. The shell crystal structure modification in oysters recalls the eggshell thinning in the California brown pelican and suggests that calcium metabolism is one of the physiological processes affected by chlorinated hydrocarbon accumulation.



3—Log-log plot of the chlordane concentration factor (K_c) versus the chlordane dosing concentration level demonstrates that the ratio of oyster tissue chlordane concentration to a given water chlordane concentration exposure is not constant. The chlordane scale is the tissue chlordane concentration divided by the chlordane dosing concentration, and the abscissa scale is the negative log of the chlordane dosing concentration.

Table 4—Trace Metal Concentrations in Sediments—Parts Per Million Dry Weight

	Baltimore Harbor	*Potomac Estuary*	*Bay Bridge*	*Rhode River*	*Chester River*
Zinc	2599.9	75—1050		0—80	7—322
Lead	1502.5	5—170	11—60	8—130	2.3—60
Cadmium	192.3	0—0.6		0.2—4.3	0.12—2.0
Copper	320.1	8—73	18—54	3—120	1.6—35
Chromium	3034.9	7—87		9—54	2.2—110
Iron		8,000—87,000		7,300—38,000	1,600—41,200

Perhaps the most practical finding from the laboratory toxicity studies is an indication of how the steady state concentration of chlordane in oysters changes as the chlordane exposure level changes. If a concentration factor (K_c) for chlordane uptake by oysters is defined as the chlordane level accumulated in tissues divided by the chlordane exposure concentration in the water, it might be expected that K_c would be a constant—that is, the chlordane level accumulated in tissues would increase directly as exposure concentration increases. Actually, the experimental data show that K_c is not a constant, but is *inversely proportional* to the exposure concentration. At low concentrations of chlordane, the ratio of oyster tissue chlordane content to chlordane concentration is relatively greater (when steady state is reached) than at higher concentrations.

This inverse relationship, shown by the log-plot in Fig. 3, means that chlordane concentration would have to be less than 0.22 ppt in the water environment inhabited by oysters to stay below the previously set "alert level" of 30 ppb in oyster tissues. Furthermore, this same curve indicates that the chlordane level in the water environment would only have to exceed 6.5 ppt to raise chlordane levels in oyster tissue above the newly proposed interim alert level of 300 ppb.

Further work to develop this type of K_c relationship for other chlorinated hydrocarbons and for trace metals is needed to establish effective water-quality monitoring programs. Such K_c relationships would permit the prediction of concentration levels in shellfish stocks directly from water quality data without the need for extensive shellfish monitoring programs.

Trace Metals

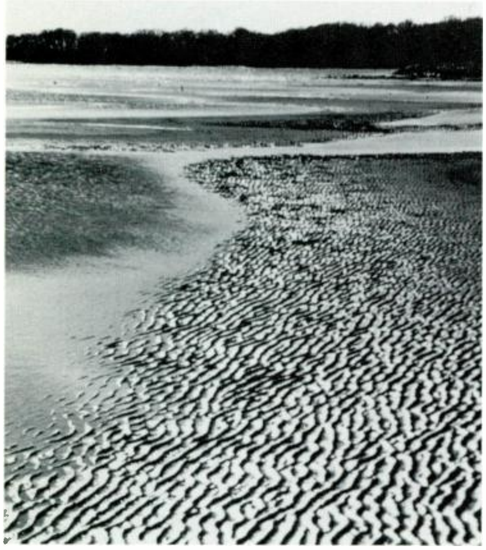
Many metals such as iron and copper in small quantities are essential to the well-being of organisms. However, excess concentrations of these metals can lead to adverse effects that weaken or kill. In Chesapeake Bay, there has long been concern over the possibility of accumulations of excess amounts of trace metals in shellfish, picked up from the sediments of the Bay and its rivers. Thus, routine analyses of shellfish meats are conducted by the Public Health Service.

To obtain a better understanding of the possible environmental sources of trace metals, six metals (chromium, zinc, iron, copper, cadmium, and lead) generally considered hazardous to human health were investigated in the Chester River Study. The concentrations found in Chester River sediments were compared with those found by other laboratories at other locations in the Chesapeake Bay region. The areas selected were known to have high or low levels of trace metal contamination. For example, Baltimore Harbor was chosen for comparison because of its highly industrialized character. The Rhode River on the western side of Chesapeake Bay south of Annapolis was chosen because of its light to moderate urban and industrial inputs. The Chester River, of course, has its contributions primarily from the region's agricultural activity.

The trace metal findings for the five areas chosen are summarized in Table 4.

As indicated, the concentrations of the six metals studied in the Chester River are, with the possible exception of zinc, comparable to those in the similar but much smaller Rhode River, both having relatively low levels.

As with the chlorinated hydrocarbon studies, trace metal concentrations were compared with grain size of the sediments examined. These comparisons indicated a relationship similar to that found for pesticides; i.e., the finer the average grain size of the sediments, the higher the trace metal concentration. This correlation is interpreted as having a direct relationship with several phenomena common to fine-grained sedimentary materials rich in clay minerals. For example, clays in suspensions are very efficient chemical "scavengers" and attract and adsorb several classes of materials. Once the clays have become saturated, unusual environmental conditions are required to free the adsorbed ions and compounds. Normally, the deposition of these clay materials effectively removes the bound trace metals from the water environment and it is only when there are massive resuspensions such as during major dredging operations that there is environmental concern. However, until additional laboratory studies are conducted to determine the degree of correlation between sediment levels and the amount of metal uptake in concentration tissues of organisms, further discussion of these relationships remains speculative.



Shoreline erosion of the banks of the Chester River produces extensive tidal flats, such as this deposit at Kent Island. Extensive dredging may be required to remove sediments from navigable waterways and marinas.

Shoreline Erosion

A detailed survey of 113 miles of the tidal portions of the Chester River shoreline shows that more than 90 percent of the shoreline is eroding at rates ranging from one to ten feet per year.

The eastern shorelines of the Chesapeake Bay and the river tributaries draining the Delmarva peninsula are composed mostly of weakly compacted Quaternary sands and clays deposited during glacial periods when sea level was lower than today. These deposits lack the interparticle cement of sandstones and siltstones and thus are more easily eroded than the older Tertiary sedimentary formations. Thus, the weak lowland areas bordering the Chester River are easily eroded, and the sediments produced must ultimately be deposited in some portion of the estuarine system, where they may eventually necessitate costly dredging. Sedimentation also leads to the destruction of oyster beds.

Unlike the open sea, the shallow Chesapeake Bay is subject to relatively rapid changes in water level in response to strong winds that sweep across its surface and pile up water on the downwind shore several feet above normal. This subjects the bases of weak cliffs and bluffs bordering the river to wave attack that would not occur under normal tidal conditions.

Another major cause of cliff erosion is seepage of ground water through the porous sedimentary materials forming much of the exposed banks along the Chester River. Aerial photographs of the region and direct inspection of many of the eroding banks show that many fields are plowed to the very edge of the bluffs, a practice that insures the trapping of rain water and its ultimate seepage toward the exposed cliff face where it finally emerges as small rivulets.

Thus, contrary to widespread belief that only waves and currents are responsible for extensive shoreline erosion, the study showed that rainfall and farming practices also play an important role. It is obvious that shore-protection structures designed only to eliminate the erosive action of waves and currents may not prove effective, and there is a real need to develop better shore-protection structures that take into account all the erosive forces at work.

A New Study of Upper Chesapeake Bay

Some of the major Chester River Study recommendations were: find out in detail the "when, where, why, and how" of pollution in the Bay, the Susquehanna River, and Baltimore Harbor, so that satisfactory control methods can be initiated; conduct further studies on the effects of low-level pollution on shellfish; and develop more effective methods for reducing or eliminating shoreline erosion. With a contract now in hand for an Upper Bay Survey, most of these recommendations have been realized.

The Upper Bay Survey is a joint effort of the Chesapeake Bay Institute of Johns Hopkins University (modelling) and the University of Maryland (bacteria) under a Westinghouse prime contract. The area of study includes the Bay north of the Severn River, the mouth of the Susquehanna, Patapsco (including Baltimore Harbor), and the Chesapeake and Delaware Canal. As in the Chester River Study, scientists collect physical and chemical data on the water and take samples and measurements of bacteria and contamination concentrations in shellfish, finfish, plankton, bottom sediments, suspended sediments, water, and airborne dust particles. Toxicological experiments in wet laboratories will produce cause and effect data on the biota, primarily shellfish. Effect data, a model accounting for sediment transport and resuspension, and the baseline survey, all taken together, should provide the tools for Chesapeake Bay resource management, which is the objective of the Upper Bay Survey.

Grounding for Industrial and Commercial Distribution Systems

A. A. Regotti
H. W. Wargo

Phase-to-ground faults are the most common kind in distribution systems. Therefore, the kind of system grounding used (if any) and the ground-fault protection applied are important. They should be carefully chosen to fit the particular application. This article, the first of two, discusses system grounding; the second will discuss ground-fault protection and detection.

Both grounded and ungrounded distribution systems are used successfully at the lower distribution voltages, and both have their proponents. At higher distribution voltages, systems are nearly always grounded but there are choices in the type of grounding to use. At all distribution voltages, the designer has a wide range of choice in the type and amount of ground-fault protection to apply.

The many choices that are possible should not be made simply on the basis of past practice. Distribution systems tend to grow in physical size and voltage level, codes and recommended practices change, and continuity of service is more important in some systems than in others. Moreover, improved ground-fault detecting devices, much more sensitive than those used in the past, have become available at reasonable cost.

Consequently, each distribution system should be studied on its own merits. Then the necessary tradeoffs can be made to arrive at the most economical system that will provide the level of equipment protection, personnel protection, and service continuity deemed necessary for that particular system.

Most system faults have always been of the phase-to-ground type, so the best system is one in which a ground fault results in the least total cost. That is often a grounded system. The method of grounding (if any) can be determined confidently once the system parameters and operations are known.

Grounding methods are very dependent on system voltages. For these articles, low-voltage distribution systems are defined as 600 volts or less; medium-voltage systems, 2.4 to 15 kV; and high-voltage systems, above 15 kV. Since most industrial and commercial systems are of medium or low voltage, high-voltage grounding is not discussed here except to say that almost all high-voltage systems are solidly grounded.[1]

Ungrounded Systems

An ungrounded system is defined as a system of conductors with no intentional connection to ground. A simple one is diagrammed in Fig. 1. Since all circuit conductors are separated from each other and ground (earth) by an insulating medium (normally rubber and/or air), the conductors are capacitively coupled to each other (phase to phase) and to ground. The phase-to-phase capacitive coupling has little influence on the grounding characteristics of the system, so it is omitted from this discussion.[2]

The voltage from each phase to neutral equals the voltage from each phase to ground, and the neutral is at ground potential, so long as none of the conductors is grounded. However, if one conductor develops a bolted fault to ground (Fig. 2), the system neutral is in effect shifted from ground by a voltage value equal to the system line-to-neutral voltage, thus increasing the voltage stress on the insulation of the unfaulted conductors. (See *Effects of Ground Fault in Ungrounded Systems*, p. 42.)

The ungrounded system's main advantage is that it can continue to operate with an accidental ground on any one phase, because only the small capacitive current (I_G) flows. However, if the first ground fault is not cleared before a second one occurs on another phase, a double-line-to-ground fault has occurred. The resulting line-to-line fault operates phase-operated protective devices in one or both circuits and can cause considerable damage and downtime. (Phase-operated protective devices are those operated by current flowing in the phase conductors.)

Moreover, the capacitive-coupled (ungrounded) system is very likely to produce transient overvoltages due to arcing line-to-ground faults and to series resonance. (Arcing ground faults are also called "restriking," "sputtering," or "intermittent" ground faults.)

Arcing ground faults have been observed to create overvoltages of five to six times normal voltage. The mechanism by which these overvoltages occur is rather lengthy.[1] In brief, they are due to the ability of the coupling capacitance to store captive ("trapped") voltages between successive restrikes, thereby shifting the system neutral above ground level many times the normal bolted line-to-ground fault displacement. The likelihood of an arc restriking is much greater at the higher distribution voltages than the voltage difference alone would suggest. The reasons are that the arc current on an ungrounded system is directly proportional to voltage, and the voltage gradient and rate of rise are greater at the higher distribution voltages than they are at lower voltages. Thus, the likelihood of transient overvoltages due to intermittent grounds becomes much greater with increasing system voltage.

Series reasonance results from the inductive reactance of the system apparatus in the faulted circuit. The ratio of the inductive reactance of the line-to-ground circuit versus the system coupling capacitive reactance to ground determines the degree of overvoltage on the system. When the inductive reactance is equal to the resultant capacitive reactance of the two unfaulted phases (a resonance condition), the system neutral-to-ground voltage can become infinite if no losses exist.[1] However, in actual systems there are always some losses, so the transient overvoltage is limited to some finite value (normally six to ten times normal line-to-neutral voltage). Even with that limitation, the test voltage capabilities of equipment can be exceeded (Table 1).

A particular type of inductive coupling known as ferroresonance exists when the faulted circuit inductance has an iron circuit that can become saturated. The resulting varying inductance can cause the saturated inductive reactance to match the system capacitive reactance. This condition is very probable when three-phase poten-

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tial transformers are applied on a three-phase ungrounded system.

Because the overvoltages due to arcing ground faults and series resonance are caused by excessive neutral displacement with reference to ground, the amount of overvoltage can be held to tolerable limits if the neutral voltages can be stabilized. Stabilization is accomplished by grounding the system.

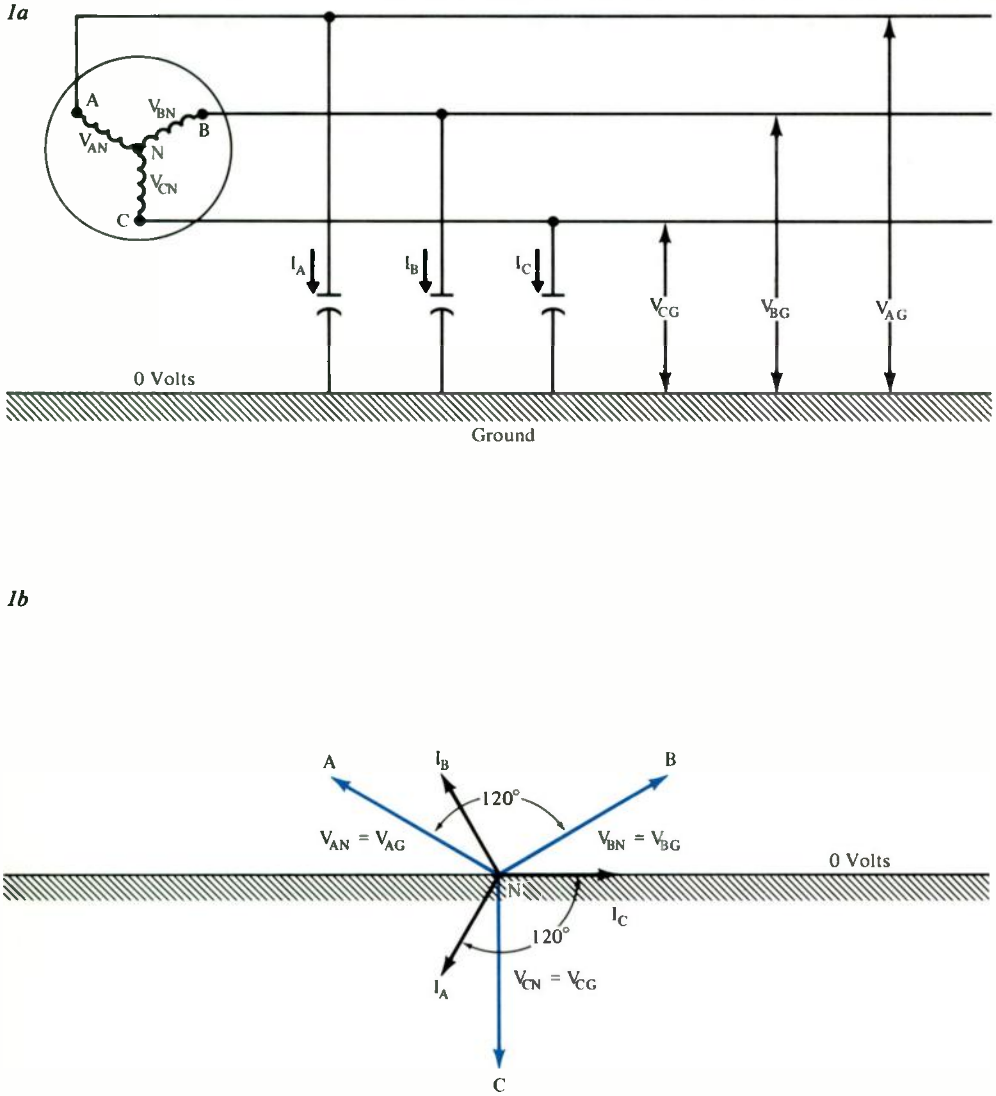
Grounded Systems

A grounded system is defined as a system of conductors in which at least one conductor, usually the system neutral, is intentionally grounded either solidly or through a resistor or other current-limiting device. Both solid and resistance grounding can limit transient overvoltage to a safe level (250 percent of normal voltage); therefore, other system parameters determine the choice.

Solid Grounding—Ground-fault currents in solidly grounded industrial distribution systems are theoretically equal to three-phase fault currents. Thus, solid grounding can provide some protection against ground faults by allowing enough fault current to flow to open phase-operated protective devices. However, that kind of ground-fault protection often is not sufficient. Specific ground-fault protection will be discussed in the second article.

Generators are not usually solidly grounded. They cannot withstand the fault currents that result from a ground fault in a solidly grounded system unless they are specifically designed for solid grounding.

Resistance Grounding—The grounding resistance required to limit overvoltages to a safe level is determined by use of the following ratios: Zero-sequence resistance must be equal to or less than one-third of the system phase capacitive reactance to ground, and the ratio of zero-sequence resistance to zero-sequence reactance must be equal to or greater than two.[2] Those limitations can result in ground-fault currents from approximately one ampere to hundreds of amperes. The minimum ground-fault current depends on the sys-



Effects of Ground Fault in Ungrounded Systems

Theoretically, in a balanced three-phase system, the currents in all three lines are equal and 120 degrees apart (Fig. 1b). The vector sum of the three capacitive phase currents (I_A, I_B, and I_C) is equal to zero at the ground point, which also results in the generator neutral being held at ground potential by the balanced capacitive voltages to ground (V_{AG}, V_{BG}, and V_{CG}). Thus, although an ungrounded system does not have an intentional connection to ground, the system is actually capacitively coupled to ground.

If one system conductor, phase C for example, becomes faulted to ground (Fig. 2a), then phase C and ground are at the same potential—zero volts (Fig. 2b). The voltage of the other two phases with reference to ground is increased to the system phase-to-phase voltage. Furthermore, the voltages to ground are now only 60 degrees out of phase.

For a bolted phase-to-ground fault, the neutral (N') is shifted from ground by a value of voltage equal to the system line-to-neutral voltage (V_{CN}). This causes the capacitive coupling voltage of the two unfaulted phases to increase from V_{AN} to $V_{A'G}$ and V_{BN} to $V_{B'G}$. The voltages $V_{A'G}$ and $V_{B'G}$ define the potentials appearing across the distributed capacitance of the ungrounded system; they result from the neutral displacement when phase C is faulted to ground. Voltages $V_{A'N'}$ and

1—Simplified diagram of an ungrounded distribution system illustrates the capacitive coupling of the phase conductors to ground. As long as none of the conductors is grounded, the voltage from each phase to neutral equals the capacitive coupling voltage from each phase to ground, and the neutral is at ground potential.

tem charging current, and the maximum should be dictated by the sensitivity of the ground-fault protective devices applied. To be adequate for equipment protection, the protective devices should detect a ground-fault current that is 10 percent of the maximum possible.

For *high-resistance grounding*, the value of the resistor is normally dictated by the first ratio given above, which states basically that the current through the resistor should be equal to or greater than the charging current of the system. Charging current is essentially the ground current (I_G) calculated as indicated in the "box" below.

Use of such grounding resistance results in low ground-fault current, providing a distribution system that is similar in operation to an ungrounded system without the possibility of damaging transient overvoltages from arcing grounds and resonance. Since the system is, in effect, an ungrounded system, the National Electric Code (NEC) does not require ground-fault protection.

High-resistance grounding results in the least system disturbance during single-line-to-ground faults, which are the most prevalent type. Consequently, it is the preferred grounding method, provided that a reliable maintenance program and crew are available.

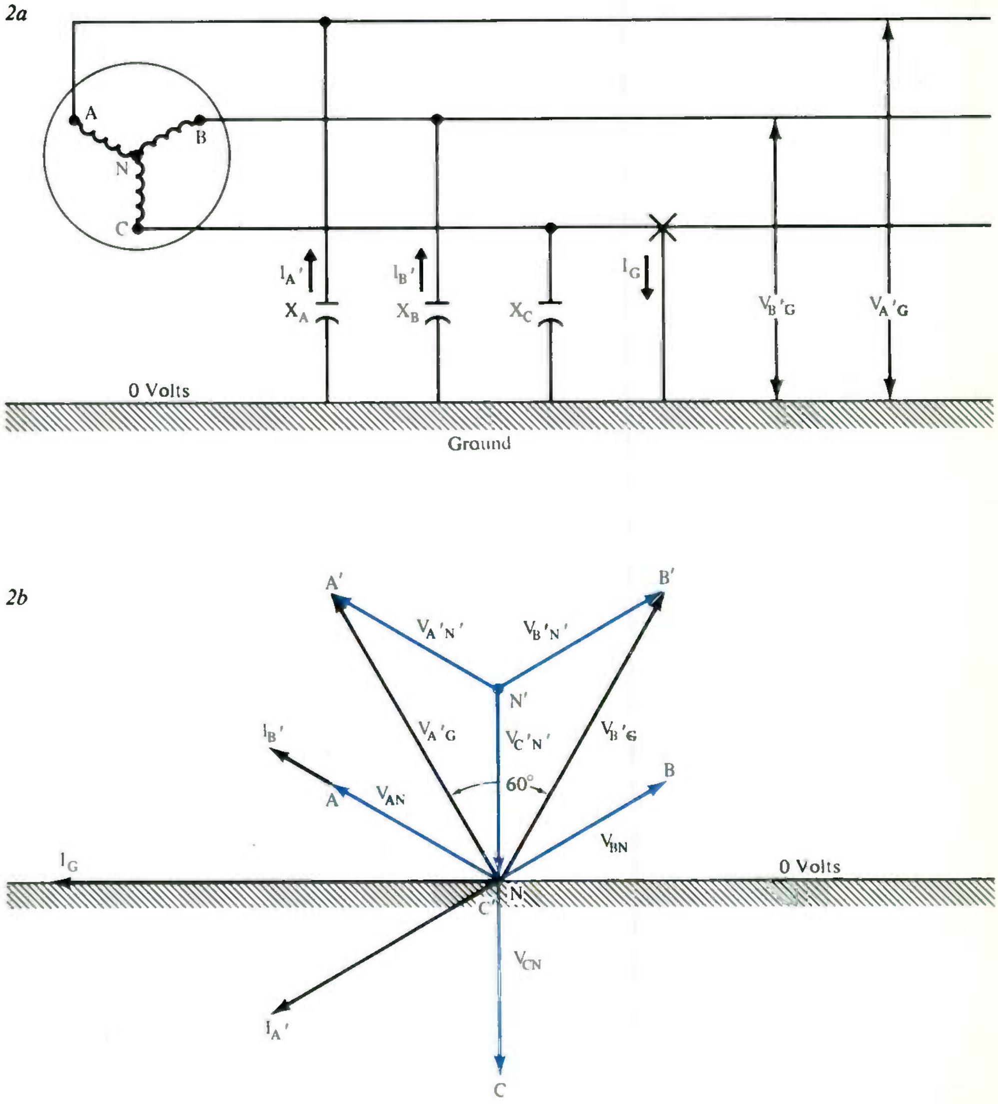
For *low-resistance grounding*, the value of the resistor is normally dictated by the second ratio given above ($R_0/X_0 \geqq 2$) and by the sensitivity of the ground-fault protective devices applied. Low-resistance grounding should be used if maintenance personnel are not available to remove a ground fault within a reasonable period, because it causes the faulted circuit to be isolated immediately by ground-fault protective devices.

Low-Voltage Systems

Ungrounded—An ungrounded system has the fundamental advantage that it can operate with an accidental ground on any one phase. Since most faults are ground faults, it is logical to assume that the system

$V_{B'N'}$ assume the same vectorial direction as their prefault voltages V_{AN} and V_{BN}.

Even though the capacitive voltages are distorted during a single-line-to-ground fault, the system remains balanced (only the neutral being shifted above ground). Therefore, the phase-to-phase voltages (V_{AB}, V_{AC}, and V_{CA}) have not changed in magnitude or phase relationship (120 degrees). Ground current (I_G) is the vector sum of the two currents $I_{A'}$ and $I_{B'}$ (which are 90 degrees ahead of their respective voltages $V_{A'G}$ and $V_{B'G}$), where $I_{A'} = V_{A'G}/X_A$ and $I_{B'} = V_{B'G}/X_B$. X_A and X_B are the system capacitive reactances calculated from the capacitances of the elements of the particular distribution system. This ground current value is used to determine the maximum grounding resistance for high-resistance grounding.



2—If one conductor in an ungrounded system is faulted to ground, the system neutral is shifted from ground by a voltage value equal to the system line-to-neutral voltage. The system can continue to operate, but the next accidental ground on another phase results in a line-to-line fault. Moreover, arcing ground faults and series resonance can cause destructive overvoltages by excessive displacement of the neutral.

least disturbed by a fault is an ungrounded system.

The authors' experience indicates that this logic is sound for low-voltage systems, provided the maintenance crew is capable of locating and isolating the initial fault in a reasonable amount of time after being alerted by a ground-fault alarm. (Alarming is discussed in the second article.) A reasonable amount of time is the first opportunity that a circuit isolation to repair the faulted apparatus would not result in unacceptable loss of production, since continuity of service is the original premise for the ungrounded system.

The major objection to an ungrounded system is the occurrence of system transient overvoltages resulting from arcing grounds and resonant conditions, and the resulting additional voltage stresses on the unfaulted phase insulation due to the neutral shift. However, as Table 1 shows, the insulation furnished for low-voltage systems is liberal and normally can withstand the usual overvoltage stresses (up to six times normal) that can be expected on a practical ungrounded system. Many ungrounded 480-volt systems have a history of good continuity of service and freedom from multiple equipment failures or evidence of damaging overvoltages. Such success, however, is related to the speed with which ground faults are located and isolated.

Grounded—In practice, the theoretical ground-fault current is probably never realized. Since the fault driving voltage (line-to-neutral voltage) is low to begin with, fault impedance and arc voltage greatly reduce the ground-fault current. Experience with low-voltage systems shows that the excessive damage credited to ground-fault currents is often due not to high currents but to low currents that were permitted to flow for a long time because they were not detected by phase-operated protective devices. This deficiency has been recognized by revision of the NEC to require ground-fault protection for particular conditions.[3]

*Table 1—Transient-Voltage Test Capabilities of System Apparatus**

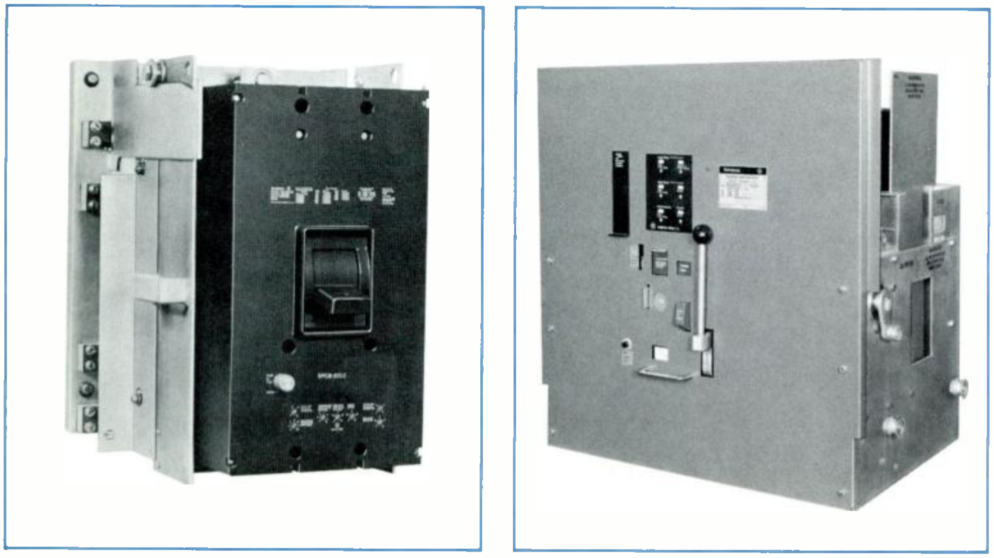
	Normal Rated Line-to-Line Voltage of Power Source									
	480		*2400*		*4160*		*4800*		*13,800*	
Apparatus	*Test kV*	*E Margin*	*Test kV*	*E Margin*	*Test kV*	*E Margin*	*Test kV*	*E Margin*	*Test kV*	*E Margin*
Motors	1.92	6.92	5.6	4.04	9.0	3.75	10.2	3.68	27.4	3.44
Dry Type Transformers	4.0	14.4	10.0	7.2	12.0	5	12.0	4.33	31.0	3.89
Liquid Transformers	10.0	36	15.0	10.8	19.0	7.91	19.0	6.86	34.0	4.27
Switchgear	2.2	7.94	19.0	13.7	19.0	7.91	26.0	9.38	36.0	4.52

*Compilation of industry standards.
Test kV: One-minute 60-Hz factory test values. For motors, these values are not official but generally accepted to be equal to twice normal line-to-line voltage *rating* plus 1000 volts.
E Margin: The ratio of test kV to normal system line-to-neutral kV.

The requirement has resulted in inclusion of integral ground-fault protection in three standard lines of Westinghouse low-voltage circuit breakers—the Type DS breaker made by the Switchgear Division and the Quicklag ground-fault circuit breaker and SCB breaker supplied by the Low-Voltage Breaker Division. However, the conditions specified by the NEC result in application of many protective devices that do not have specific provisions for ground-current detection, so phase-operated devices still must detect ground faults in many circuits. Thus, when low-voltage systems are grounded, *solid grounding* is usually recommended to achieve the highest probability that the phase-operated devices will operate on ground-fault currents.

However, *high-resistance grounding* is highly recommended for continuity of service and for mitigating damage if the maintenance crew can quickly locate and isolate an initial fault.

Low-resistance grounding is not recommended because, as stated, so many breakers in low-voltage systems do not



(Photos)—*Integral ground-fault protection is included in these Westinghouse low-voltage circuit breakers. They are, left to right, the SCB and Type DS breakers.*

3—(Right) *Operation of a single fuse that does not open the other two phases may not fully isolate a ground fault. In this three-phase motor circuit, for example, the colored arrows indicate a large initial ground-fault current in phase 2 that blows the fuse in that phase; the black arrows indicate a smaller ground-fault current that continues to flow in phases 1 and 3. Such a fuse operation also results in single-phasing of the motor, which could cause overheating. Safety requires use of a backup circuit breaker with ground-fault protection.*

have specific provisions for detection of ground current. Low-resistance grounding can permit flow of ground currents that are high enough to be damaging but too low to cause phase-operated devices to operate.

Medium-Voltage Systems

Ungrounded—Ungrounded systems are not recommended because of the possibility of transient overvoltages and also because of the relatively small overvoltage allowance for medium-voltage equipment, especially motors (Table 1).

Grounded—Any of the three methods of grounding, or modifications of them, can be used.

Solid grounding is seldom recommended because the large ground-fault currents can cause extensive equipment damage. It is especially bad when rotating equipment, such as motors or generators, is connected at the same voltage level as the ground source.

One use, however, is where primary fuses are applied as protective devices on the high side of the delta-wye transformer bank and are expected to isolate the transformer bank for a secondary ground fault. Another is in distribution networks with extensive lightning exposure, such as outdoor utility lines; it allows use of lightning arresters of lower voltage rating than would otherwise be needed, thereby reducing the total initial cost of arresters.

High-resistance grounding is the best, if a good maintenance crew is present, because it results in the least disturbance from the most prevalent faults. Another consideration on medium-voltage systems is the amount of system charging current present. Where the charging current is excessive, 50 amperes for example, the destructive effect of such current requires that the fault be isolated by ground-fault protective devices. Usually, however, the charging current is 5 amperes or less, so ground-fault alarming (discussed in the second article) is sufficient.

Low-resistance grounding should be applied for immediate isolation of the faulted circuit if personnel are not available to answer a ground-fault alarm and/or if rotating equipment is in the system. The value of the grounding resistance should be determined by the sensitivity of the relay applied. Since adequate relaying detects a 10-percent fault, the resistor must be sized to provide a current 10 times the system maximum ground-fault sensitivity. Zero-sequence ground-fault relaying can have a sensitivity of 5 to 15 amperes primary current, so the resistor can be sized to provide from 50 to 150 amperes maximum ground-fault current. Such a resistor would satisfy the requirement that the ratio of R_0 to X_0 be equal to or greater than two in order to suppress any system transient overvoltages.

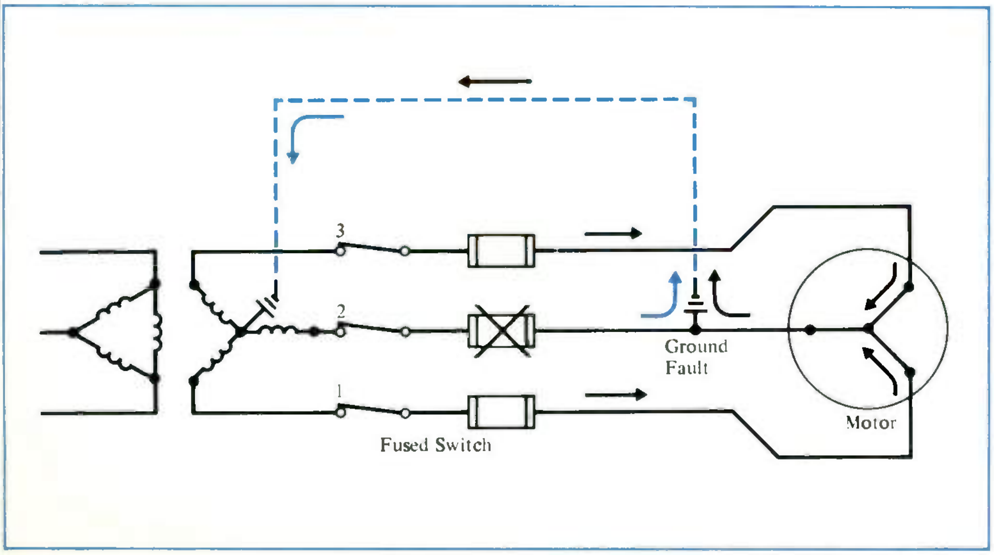
Reduction of the ground current would also prevent most fuses from operating before the ground-fault protection operates. That is desirable, as fuses are single-phase devices and do not always isolate a ground fault as desired (Fig. 3).

Conclusions

In general, the type of grounding for *low-voltage systems* is dictated by the type of processes involved, the critical nature of the load, and the availability of maintenance personnel. If the process is such that abrupt outages would cause excessive expense, and a prudent maintenance program has been established, an ungrounded system or high-resistance grounding is preferred over low-resistance and solid grounding.

If the process is less critical or maintenance personnel are not always available, then a solidly grounded system is preferred. This type should be protected as much as possible with separate ground-fault sensing devices that automatically isolate the faulted portion of the system.

Medium-voltage systems should not be operated ungrounded because of the lower overvoltage allowance for medium-voltage equipment. If a well established maintenance program and crew are available, high-resistance grounding is recommended. If the initial ground fault is to be isolated automatically, the system should be low-resistance grounded. With zero-sequence ground relaying throughout the system, the maximum ground fault can be limited to approximately 150 amperes.



REFERENCES:

[1] *Electric Transmission and Distribution Reference Book*, fourth edition, Westinghouse Electric Corporation, East Pittsburgh, Pa., 1950.

[2] *IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems*, Standard 142, 1972. (ANSI Standard C114.1-1973.)

[3] National Electrical Code, 1971.

[4] R. F. Karlicek and E. R. Taylor, Jr., "Ferroresonance of Grounded Potential Transformers on Ungrounded Power Systems," *IEEE Transactions*, Aug. 1959, pp. 607-18.

[5] *Silent Sentinels, Westinghouse Protective Relays*, Westinghouse Relay Division, Newark, N.J., 1950.

[6] A. A. Regotti and H. S. Robinson, "Changing Concepts and Equipment Applied on Grounded Low Voltage Systems," *IEEE-IGA Transactions*, May/June 1972.

[7] D. Beeman, *Industrial Power Systems Handbook*, McGraw-Hill, Inc., New York, N.Y.

PACE Power-Plant Control System Provides Operating Flexibility and High Plant Availability

T. C. Giras
P. A. Berman

Operating efficiency has become more important than ever for generating plants in this era of fuel shortage. Moreover, plants for peaking and intermediate generation must be able to start up rapidly, increase or decrease their output rapidly, and have high availability for service. All of those requirements are met by the new PACE plants through use of a hybrid control system that makes it practical to operate three generating units in an efficient and flexible combined cycle.

Over the past decade, electrical energy shortages have resulted in the use of many peaking units at operating levels in excess of their optimum economic levels. Those peaking units are employed to supply the intermediate load band, along with former base-load units that have had to be shifted to intermediate service. The latter are usually older units that lack modern control systems and therefore lack the control flexibility that intermediate generation requires. In short, the intermediate load band often is not being supplied as efficiently and as flexibly as it could be.

In addition, large interconnecting ties require increasingly close control of area generation to meet the security requirements of the grid, i.e., to keep the system from breaking up. Such control can best be provided by reserve power supplied by peaking and intermediate plants that are able to start up rapidly and alter their power outputs rapidly in response to the grid's dynamic needs.

PACE combined-cycle plants can meet those needs for increased efficiency and flexibility because they blend the best features of peaking and base-load generation by combining one steam and two gas turbines. Gas turbines are fast in starting up and in responding to changes in power demands, but they are relatively inefficient by themselves; steam turbines are slower in startup and response but are more efficient. The PACE design combines them in such a way as to use waste heat from the gas turbines to generate steam for the steam turbine. (See *PACE Power Plants* at right.)

The result is a plant that has an excellent heat rate when the steam turbine is operated with one or both gas turbines, and yet has fast startup and control flexibility. Heat rate is 8000 Btu per kilowatt hour with the steam turbine and both gas turbines operating; for comparison, the heat rates of typical modern steam base-load plants and gas-turbine peaking plants are, respectively, about 9000 and 12,000 Btu per kilowatt hour. The gas turbines can be operated independently of the steam turbine, and of each other, for flexible plant operation. Startup of the entire plant from hot standby requires about one-fourth the time required by typical steam plants.

Thus, although the PACE plant is intended primarily for intermediate generation, it can provide service ranging from peaking to base-load generation—as needed and as influenced by the relative costs of fuels. To do so, the PACE plant requires a capable control system. Simple subsystem controllers for each section of the plant, coordinated by the operator to meet the needs of the power grid, are no longer adequate. Total centralized control is needed to integrate the operation of the plant components. The control system must coordinate all elements of the PACE system through all operating modes from startup to full load, it must help provide maximum plant availability, and it must enable the plant to participate in overall control of the power grid.

PACE Plant Control System

To meet those requirements, the control system uses all the technologies—analog, digital, and wired-logic—integrated in such a manner as to assure generation availability. All elements of the control system have been field proven in power generation systems for a number of years. Like the rest of the PACE plant, the control system is of modular design. Each turbine-generator unit has its own controls, so loss of any control function affects only one unit.

The system includes wired logic for the plant protection subsystems, solid-state analog control, and two Prodac 2000 digital computers. (See diagram, pp. 48 and 49.) One computer gathers information on critical plant parameters, analyzes it, and displays it; the other has a real-time digital-control software package that implements coordinated control of the total plant by optimizing the operation of the analog control system, which actually runs the plant. With the computers in service, the plant can be operated at any degree of automation desired by the operator. Loss of either or both computers results in no loss of plant generation, since the analog control can operate the plant. Critical analog loops are redundant in all plant modules.

A single operator can control the entire plant from the control room, although an additional man is required for about one shift a day to take steam samples, check the chemical feed system, and perform a walk-through inspection of the various electrical and mechanical equipment modules outside the control room. Any failed control component can be repaired or replaced by the plant instrument technician during the regular day shift without a total loss of generation capability.

Plant operation includes both transient and steady-state modes, which are defined in the control room by the state of bistable or multistable switches, breakers, or valves, and by the state of closed-loop controls such as on/off switches. The transients are long-term modes, such as acceleration and the building up of steam pressure. Steady-state operating modes are:

1) Hot standby, ready to start. Steam-cycle components are kept hot by electric heaters. The plant can reach full load from this mode in approximately one hour.

2) Running mode. The turbine-generator units selected for operation are running at 3600 r/min and all associated auxiliaries are in normal operation. Excitation has been applied to the generators and all equipment is ready for synchronization with the line. The running turbines are operating primarily on speed control, and the afterburners (which are auxiliary firing units in the heat-recovery steam generators) are on. The steam turbine bypass valve acts as a back-pressure control, opening and closing as needed to maintain constant

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pressure in the main steam header.

3) Power generation, gas turbines only. When the steam turbine is not needed for power generation or is shut down for routine maintenance, the gas turbines can be used alone to generate power. Startup to base load takes about 35 minutes. The steam generated can be bypassed to the condenser, or the heat-recovery steam generators can be drained and vented.

4) Power generation, combined cycle. Ordinarily, the two gas turbines are synchronized first and then the steam turbine. The steam temperature required to roll the steam turbine (determined by the rotor temperature) is attained by loading the gas turbines and/or firing the afterburners. It is also possible to start the plant with one gas turbine and the steam turbine and then bring the second gas turbine on line later.

Regardless of the plant operating configuration (the combination of turbine-generator units selected by the operator), the control system offers a choice of four

PACE Power Plants

The first Westinghouse PACE 260 combined-cycle power plant is in service at the Comanche Station of Public Service Company of Oklahoma. Three others are being installed at power stations of the Comisión Federal de Electricidad in Mexico, and 13 more have been ordered by various electric utility companies.

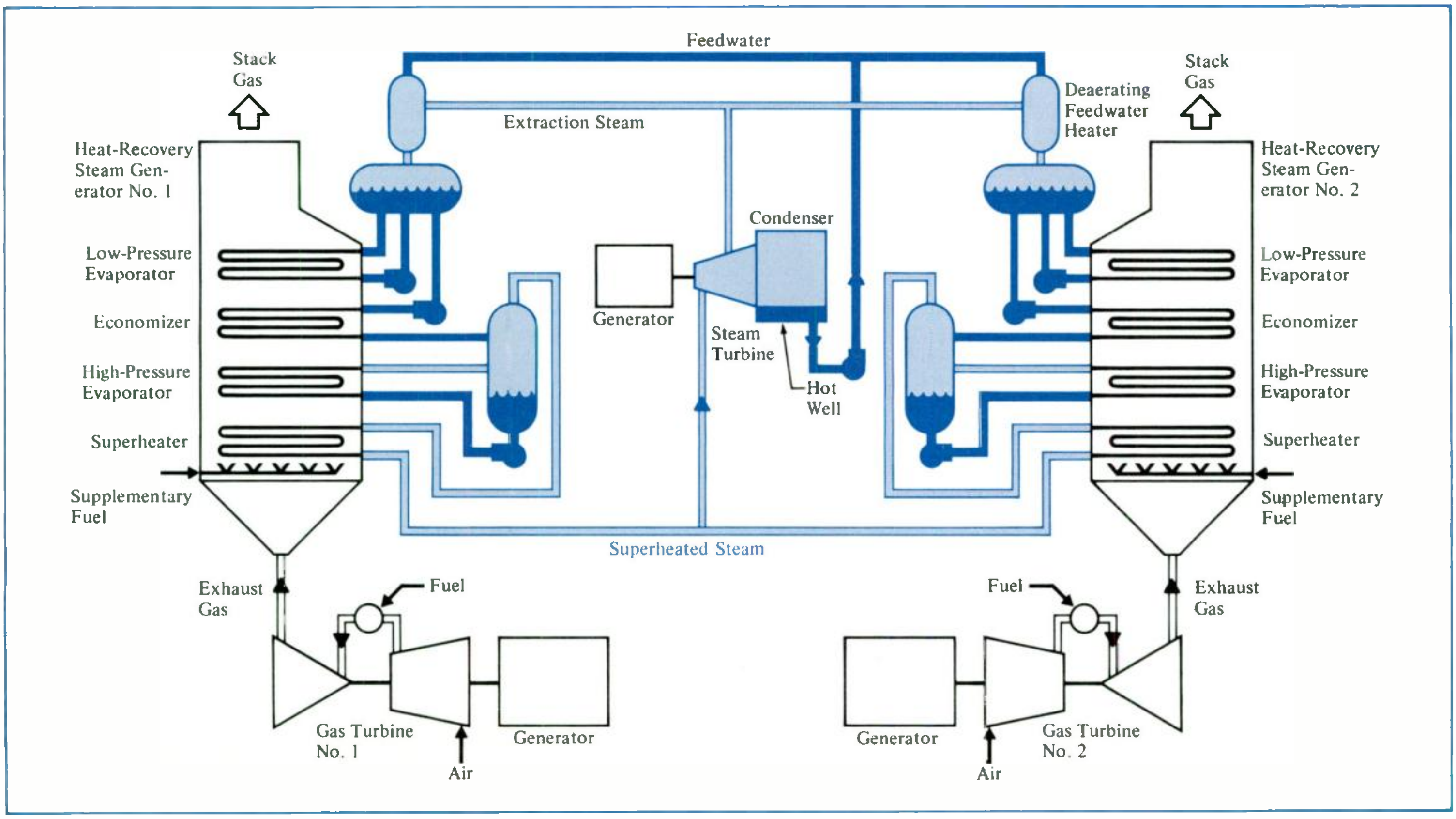
PACE is an acronym for Power At Combined Efficiencies, and 260 is the MW rating of the first plants, although other sizes can be supplied.[1] PACE plants are designed to provide the operating efficiency needed for base-load and intermediate-load operation and the fast starting, rapid load follow, and short operational lead time important in peaking and intermediate operation.

PACE plants are packaged pre-engineered combined-cycle power plants that use the exhaust energy from two gas turbine-generator units to develop steam for a conventional steam turbine-generator unit, with a consequent improvement in efficiency over that obtainable with gas turbines or steam turbines alone. The plants burn either gas or oil. Because the steam cycle provides only about half of the plant output, the need for cooling water is approximately half that of a conventional all-steam power plant of the same size.

All major components are standardized packaged units that are assembled and stocked at the factory. This approach results in a power plant that costs less and can be erected in a much shorter time than conventional fossil-fueled or nuclear power plants of the same size.

The entire plant, including the three turbine-generator units, two heat-recovery steam generators, and a control room, can be located on a site approximately 250 feet square. Auxiliaries such as lubrication systems, gages, motors, and local controls are packaged in weatherproof acoustical enclosures adjacent to each turbine.

The gas turbines used are the W501 model.[2] Each exhausts into its own heat-recovery steam generator, where additional fuel is burned. The hot gases generate steam, which is supplied to a common header at 1200 psia and 950 degrees F. From there it goes to the single-cylinder axial-exhaust steam turbine. All three generators are hydrogen cooled and designed specifically for the PACE plants.



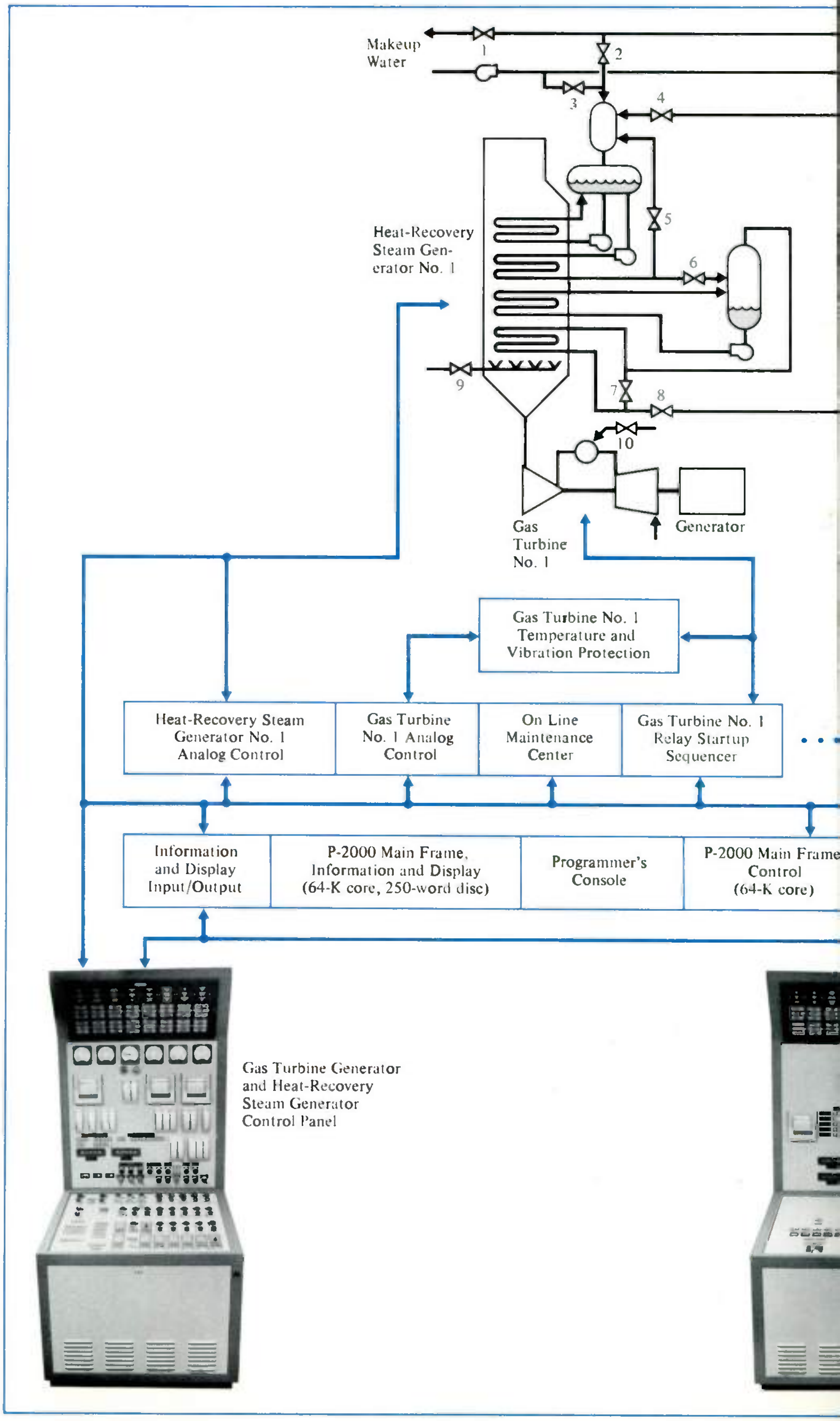
control operating levels. From highest to lowest level, they are: plant coordinated control, operator automatic control, operator analog control, and manual control. (See Table 1.) It is not necessary for all generating units to be operated at the same level of control. One may be at the operator analog level, for example, and the others at operator automatic.

Plant Coordinated Control

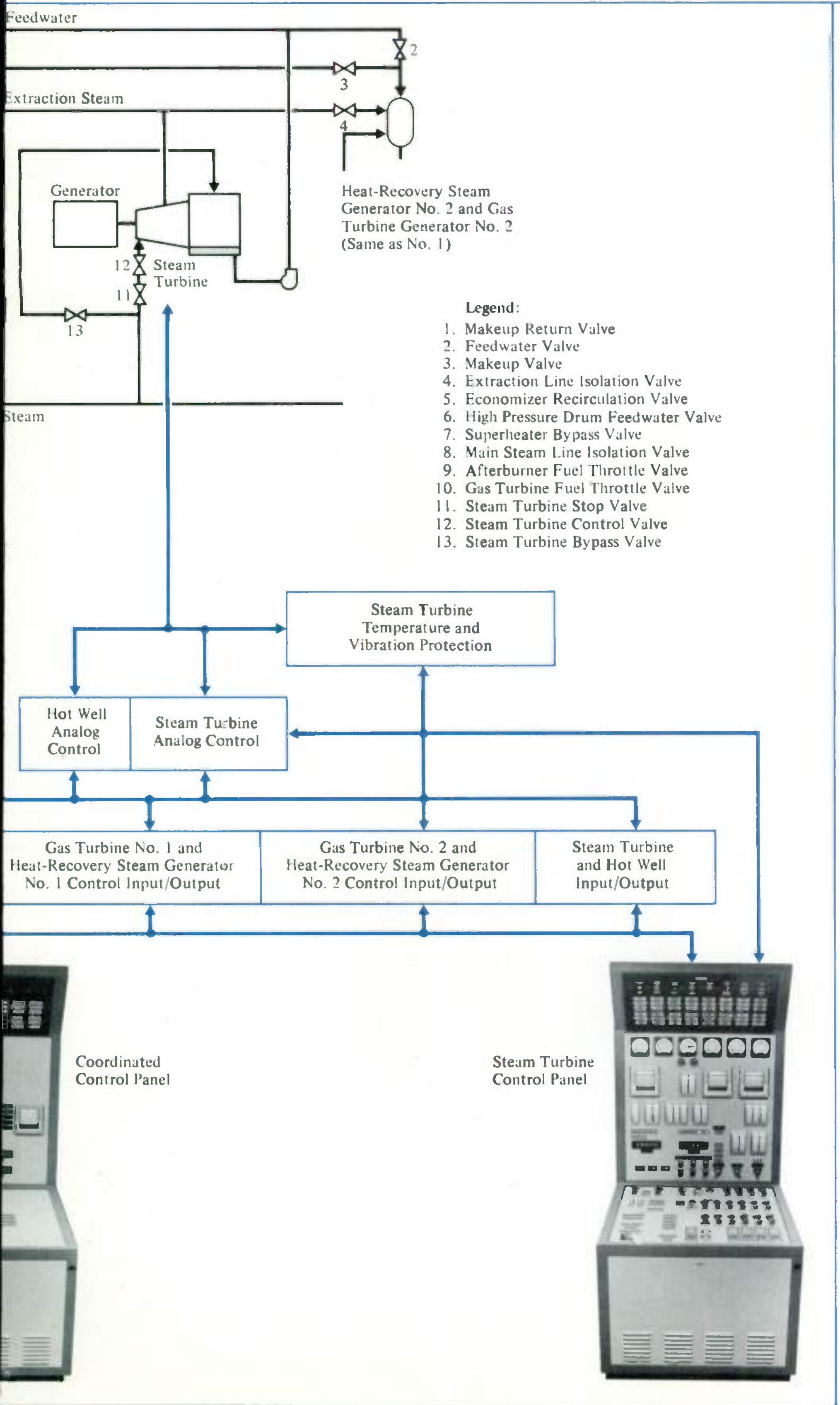
This level of control operates the plant automatically from hot standby to the preset desired power output. Operator activity is limited to selecting the fuels, the plant operating configuration, and the desired power output. If plant coordinated control is selected when the plant is in the hot standby mode, the control system coordinates startup, synchronizing, and loading of all units. The sequence of operations is arranged so that at any point at which a preset desired power output is reached, the plant will be operating on the optimum heat-rate curve. If all equipment is generating power when coordinated control is selected, only loading is coordinated among the turbine-generator units.

The control system is programmed for quick plant startup and loading, which are especially essential when the plant is used for peaking. Sequence control, ramp functions, and limit functions for the steam turbine are provided by programs in the control computer because of their inherent complexity. Gas turbine sequencing is simpler, so it is done by relay sequencers. This combination illustrates the hybrid control approach used for maximum plant availability with minimum complexity.

Steam turbine inlet and rotor temperatures are monitored to determine allowable acceleration and loading rates. The control system forces the transition from hot stand-



Simplified diagram of the control system illustrates the relationships of the main control elements and the primary plant locations where control is applied. The system incorporates two digital computers. One computer gathers, analyzes, and displays plant information; the other implements coordinated control of the plant by optimizing the operation of the analog control system that actually operates the plant.



Legend:

1. Makeup Return Valve
2. Feedwater Valve
3. Makeup Valve
4. Extraction Line Isolation Valve
5. Economizer Recirculation Valve
6. High Pressure Drum Feedwater Valve
7. Superheater Bypass Valve
8. Main Steam Line Isolation Valve
9. Afterburner Fuel Throttle Valve
10. Gas Turbine Fuel Throttle Valve
11. Steam Turbine Stop Valve
12. Steam Turbine Control Valve
13. Steam Turbine Bypass Valve

GAS TURBINE-GENERATOR AND HEAT-RECOVERY STEAM GENERATOR CONTROL PANEL

Information Available to the Operator

Gas Turbine:
- Alarm Annunciator
- Indication of Process Variables
- Recording of Process Variables
- Status Lights
- Digital Display of Selected Variables

Heat-Recovery Steam Generator:
- Alarm Annunciator
- Indication of Process Variables
- Recording of Process Variables
- Status Lights

Actions That Can Be Taken by the Operator

Gas Turbine:
- Fuel Selection
- Fuel Transfer
- Fuel Transfer Rate Selection
- Temperature Limit Selection (base or peak)
- Control Operating Level Selection
- Startup
- Shutdown
- Automatic Synchronization
- Manual Synchronization
- Automatic Voltage Regulation
- Manual Voltage Regulation
- Load or Temperature Control Selection
- Load Setpoint
- Loading Rate Selection
- Temperature Control Limit Selection (base or peak)
- Fuel Valve Reference Setting
- Inlet Guide Vane Reference Setting
- Manual Control of Lube Pumps

Heat-Recovery Steam Generator:
- Control Operating Level Selection
- Wet or Dry Operation Selection
- Automatic Startup of Afterburners
- Automatic Stop of Afterburners
- Control of Selected Pumps
- Control of Selected Valves
- Gas Temperature Setpoint

COORDINATED CONTROL PANEL

Information Available to the Operator

Alarm Annunciator
Digital Display of Selected Variables
Recording of Selected Variables
Status Lights
Logged Information
Subsystem Operating Mode Status

Actions That Can Be Taken by the Operator

Plant Load Setpoint
Loading Rate Selection
Operating Configuration Selection
Plant Automatic Startup
Plant Automatic Shutdown

STEAM TURBINE CONTROL PANEL

Information Available to the Operator

Alarm Annunciator
Indication of Process Variables
Recording of Process Variables
Status Lights
Digital Display of Selected Variables

Actions That Can Be Taken by the Operator

Operating Mode Selection
Automatic Start Selection
Shutdown
Startup
Automatic Synchronization
Manual Synchronization
Automatic Voltage Regulation
Manual Voltage Regulation
Target Speed Setting
Acceleration Rate Setting
Loading Rate Setting
Valve Position Limit Setpoint
Valve On-Off Test
Control Valve Reference Setting
Steam Turbine Bypass Valve Reference Setting
Positioning of Valves if Subloop Is on Manual

by mode to synchronous speed (for both gas turbines and the steam turbine) and, after the units have been synchronized automatically, it loads the system to the preset desired power output and regulates the generation automatically at the optimum heat rate. During operation in the plant coordinated control level, information about the plant is displayed on the coordinated control console. The information also is available as printout from the typewriter in the operations control center.

The plant's power output is controlled by the adjustable generation-demand reference, which is entered through the data entry panel. Deviations of actual generation from the desired generation initiate generation increase/decrease instructions to the gas turbines and firing-rate increase/decrease instructions to the afterburners. Coordinated control programs change gas temperature setpoints to keep steam temperature and rate of change of temperature within allowable limits.

As the value of the generation-demand reference increases, the gas turbines are loaded equally until base load is reached. Beyond that point, the afterburner firing rates are increased together until maximum gas temperature or steam pressure is reached. If the operator selects peak load operation, further increases of generation-demand reference cause turbine loads to increase until peak load is reached. This sequence is the same if only one gas turbine and one heat-recovery steam generator are in operation. The loading rate is determined by gas-temperature ramp functions that are preset in the computer.

The system automatically transfers to a lower level of control whenever a malfunction is detected in plant operation, analog or digital control hardware, or software. Since the digital and analog controls are not two separate and parallel systems but interacting controls that work together, the analog system is constantly ready for bumpless transfer to operator analog control should the control computer fail. The nature of an automatic transfer from plant coordinated control depends on the amount of plant and/or control hardware lost. The system is designed to maintain the highest level of control operation that permits safe plant operation.

Operator Automatic Control

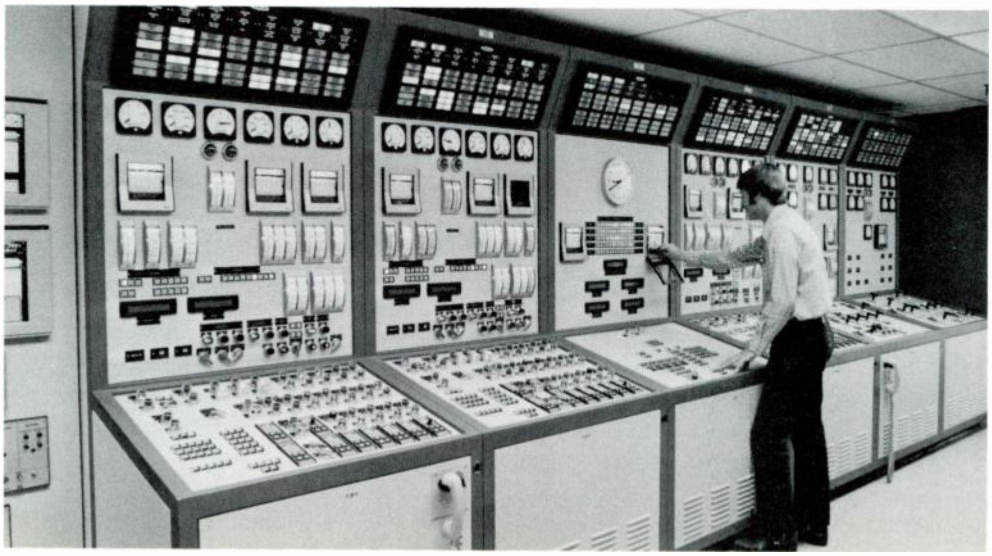
Any part of the digital control system can be selected for operator automatic control. Pushbuttons on the steam turbine control console are used to set the target speed reference and the acceleration rate of the turbine instead of using the automatic turbine start capability. The operator can choose automatic synchronization, but it is not mandatory.

If operator automatic control is selected for one or both of the gas turbines, pushbuttons on the gas turbine control consoles are used to start or stop the turbines. The operator may choose automatic synchronization, or he may use pushbuttons to operate the field breaker and the generator breaker for manual synchronization. The operator can also select generation or temperature control and enter the generation-demand reference and its ramping rate. Moreover, he can hold operation of any generating unit at an intermediate point on the reference ramp and then release it when he is ready to continue the ramp to the preset desired power output.

Operator Analog Control

The operator analog control system is designed to provide full and safe operation of the total plant or any part of the plant. It provides for startup in any plant operating configuration and for operation of the plant at any generation level. The system is capable of accepting transfer of the plant from coordinated control or operator automatic control at any time; since the digital and analog controls are interacting in both of those control operating levels, transfer to operator analog is completely bumpless.

High availability of the digital controls has been demonstrated, so the analog control system is not a complete duplication of the digital system. For example, it has no provision for keeping power output constant. The display system is confined to essential indicators, warning lights, and annunciators. However, all protective circuits are in the analog hardware.



The operations control center in the PACE control room includes these consoles for operator information and inputs. From left to right, they are for control of gas turbine No. 2 and heat-recovery steam generator No. 2, control of gas turbine No. 1 and heat-recovery steam generator No. 1, coordinated plant control, steam-turbine control, control of the plant's 5-kV electrics and auxiliaries, and an optional panel for control of the high-voltage substation electrics. The operator is adjusting a trend recorder that interfaces with the digital system. At the extreme left edge of the photo is part of the steam-turbine supervisory instrumentation.

Table 1—Control Operating Levels for PACE Power Plants

	Controlled Functions			
Level	*Total Plant*	*Gas Turbines*	*Heat-Recovery Steam Generators*	*Steam Turbine*
Plant Coordinated	Plant Automatic Startup Plant Automatic Shutdown Plant Electric Load Plant Protective Systems: Limits Runbacks Runups			
Operator Automatic		Automatic Startup Automatic Shutdown Turbine-Generator Autosynchronization Turbine Load Control Turbine Temperature Control Inlet Guide Vane Position Control Protective Systems: Overspeed Compressor Surge Temperature Limits Inlet Guide Vane Limits		Automatic Startup Automatic Shutdown Turbine Speed Turbine Load Control Deaerator and Hot-Well Level Steam Header Pressure Protective Systems: Overspeed Throttle Pressure Trips Condensate Pump Recirculation
Operator Analog		Automatic Startup Automatic Shutdown Protective Systems: Overspeed Compressor Surge Temperature Limits Trips Inlet Guide Vane Limits	Automatic Startup Automatic Shutdown Afterburner Automatic Start Afterburner Automatic Shutdown Gas Temperature Drum Level Feedwater Treatment Protective Systems: Boiler Feed Pump Recirculation Economizer Recirculation Steam Overpressure Temperature Limits Minimum Steam Temperature	Deaerator and Hot-Well Level Protective Systems: Overspeed Throttle Pressure Trips Condensate Pump Recirculation
Manual		Lubrication System Turning Gear	Feedwater Valve Recirculation Valve Superheater Bypass Valve Blowdown Valve Condensate Valve Makeup and Return Valve Fuel Valves	Lubrication System Turning Gear

During operator analog operation, valves for the steam turbine and the heat-recovery steam generators are positioned by automatic/manual stations on the control consoles. Analog subloops maintain operator-selected plant setpoints. Automatic/manual stations are provided for the afterburner fuel throttle valve, the superheater bypass valve, both feedwater valves, makeup return valve, and the economizer recirculation valve. The electric heaters that keep the shut-down steam turbine hot for faster startup are controlled as a single unit from a switch on the steam turbine control console. On-off pushbuttons are provided for manual control of the low- and high-pressure circulation pumps for the heat-recovery steam generators, the standby boiler feed pump, each of the condensate pumps, the main boiler feed pump, and the chemical feed pumps.

If the interface between the computer and the gas and/or steam turbines fails or the entire control computer is inoperative, the plant operator has analog controls to start or stop the turbines. He can select the fuel to be used, transfer from one fuel to another at a preselected rate, select the firing-temperature limit, and select the fuel control and inlet-guide-vane control signals.

Manual Control

Selected automatic control functions in the PACE control system can be manually overridden by the operator (Table 1). If manual control results in exceeding limits, it is the operator's responsibility to take the necessary action to remove the cause of the alarm unless automatic override is provided as discussed in the next section.

System Protection Features

The control system has both hardware and software protection systems to assure safe operation at any level of automatic control.

The control programming includes diagnostic programs that evaluate the validity of control actions taken by the digital computer. If a generating unit or a plant auxiliary fails, associated equipment is tripped automatically if necessary to protect the equipment. If a computer or analog element fails, control is transferred to the next lower level of control that is operable.

Redundant signal transmission assures reliability of essential measurement signals such as blade-path temperatures, gas turbine speeds, and drum levels. All critical turbine-generator temperatures and vibrations are continuously monitored and displayed independently of the status of analog or digital control centers. The gas turbine-generator units are protected against compressor surges, overspeed, and excessive exhaust temperature during automatic and operator analog operation. Throttle pressure limiting circuits protect the heat-recovery steam generators from high steam velocity and eliminate the possibility of water carryover into the steam turbine.

A priority sequence for steam turbine valve position signals assures that the protective signals override any other signals received. The priority sequence is: turbine trip runback, overspeed protection controller runback, throttle pressure limit runback, manual decrease, valve test open, and manual increase.

Steam turbine valve runup or runback is performed at four different rates as necessary to protect the equipment. Manual increase and decrease pushbuttons can be used to achieve rates of 30 or 130 percent of total operating range per minute. Automatic runback of control valves is provided as necessary, even when part of the plant is operating on analog control.

Two frequency/voltage circuits give steam turbine speed measurements within 0.1 percent error. One is for speed control and one for overspeed protection.

Hard-wired annunciator alarms are provided for all critical devices in addition to the digital computer's sequence-of-events recording. The operator can check pressure and flow measurements for failure to permit on-line substitution of redundant measuring devices in the event of malfunction of the primary devices.

PACE Control Programs

Control programs are based on the Westinghouse PROGEN software system with its efficient file management that minimizes memory storage requirements. Control chains representing the task to be performed keep program execution time low. Sequence logic is provided as necessary to assure the orderly changes in equipment status needed to bring the system on line automatically.

The computer generates the ramp function for the rate of fuel supply to the gas turbine as a function of the desired acceleration rate. After synchronization, the speed reference for the gas turbines is set for maximum load at approximately 106 percent speed to provide turbine protection but not line frequency correction. The speed reference for the steam turbine can be set by the automatic turbine startup program, the automatic synchronizer, or the operator, depending on the level of control. The rate of change of the speed reference can be adjusted up to the preset maximum rate of change by the automatic turbine startup program or by the operator. Under operator automatic control, the operator controls the gas turbine output by use of the digital system's individual pushbuttons and keyboard to set desired generation setpoints (in MW) and generation rate (in MW per minute).

Control programs for the steam turbine include automatic startup and load control up to the point where all generated steam is passing through the turbine and the steam turbine control valve is fully open.

System Quality Assurance

The sophistication of today's control systems makes dynamic factory testing of a total system essential. For PACE systems, a 100-percent real-time dynamic simulation of every signal that can enter and leave the control room makes such testing possible before the control system leaves the factory.[3]

Further, a new packaging concept used for all PACE control systems assures that the systems delivered to the field perform as well as they did at the factory. In the past, large control systems, even when operational testing was performed at the factory, were then broken down to individual components for shipment. Errors in reconnection on site were almost inevitable, and a complete retesting of the system was necessary to assure system integrity. To make that costly and time-consuming reassembly and retesting unnecessary, PACE control systems are assembled at the factory in the control room that will house the system on site.

The control room is manufactured in truck-transportable modules (three modules for the standard PACE 260 system), and interconnecting cabling between modules is kept to a minimum. Wherever cabling between modules is required, quick-disconnect devices are used to minimize disruption of the system for shipping and to speed final installation.

REFERENCES:

[1] P. A. Berman and F. A. Lebonette, "Combined-Cycle Plant Serves Intermediate System Loads Economically," *Westinghouse ENGINEER*, Nov. 1970, pp. 168-73.

[2] V. V. Schloesser, "Gas-Turbine Peaking Plant Provides 58 MW in a Modular Package," *Westinghouse ENGINEER*, Sept. 1969, pp. 130-4.

[3] T. C. Giras and P. N. Papas, "Power Plant Simulation Facilitates Dynamic Factory Operational Testing of Plant Automation and Control Systems," *Westinghouse ENGINEER*, May 1973, pp. 72-5.

[4] P. A. Berman, "Construction and Initial Operation of a PACE Combined Cycle Power Plant," ASME International Gas Turbine Conference. Zurich, April 1974.

Rapid Refueling System for Nuclear Power Plants

H. N. Andrews
G. L. Deroy
C. A. Olmstead

As the number and size of nuclear power plants increase, the search for ways to optimize their operation becomes increasingly important. The refueling process presently offers the greatest potential for operational and economic improvements. The Westinghouse Rapid Refueling System is an integrated package of equipment designs that can reduce the refueling time to less than seven days and thereby permit improvements in plant operating flexibility and nuclear fuel economics, and a reduction in manpower requirements. A planned plant maintenance program has been prepared to assure that the necessary maintenance procedures can be completed in the shorter time period required to take full advantage of the Rapid Refueling System.

Optimization studies, engineering design, and prototype testing over the past three years have resulted in a rapid refueling system that is being incorporated into Westinghouse pressurized water reactors. The optimization studies began several years ago as operating data were accumulated from Westinghouse reactors, providing statistical information on refueling and maintenance outages. Observation of plant refuelings provided records of refueling events and of the problems encountered. Utility peak-load requirements and plant maintenance and forced-outage records were analyzed. To all those statistics were added economic data—fuel cycle costs, plant equipment capital costs, and manpower requirements.

The study results indicate that significant economic and operational benefits are possible if the shutdown period required for nuclear-plant refueling can be significantly shortened compared to present requirements. This shortened shutdown period can be accomplished by refining today's refueling processes—a totally new design concept is not required. Therefore, the rapid refueling system that has been developed requires improvements in existing designs for containment, reactor, and reactor refueling equipment.

Availability Improvement with Rapid Refueling

The overriding factors that favor the advanced refueling system are economic. By reducing the time required to refuel by a factor of five, the nuclear power plant can be operated more like a fossil unit, with minimal impact of refueling on plant outage time.

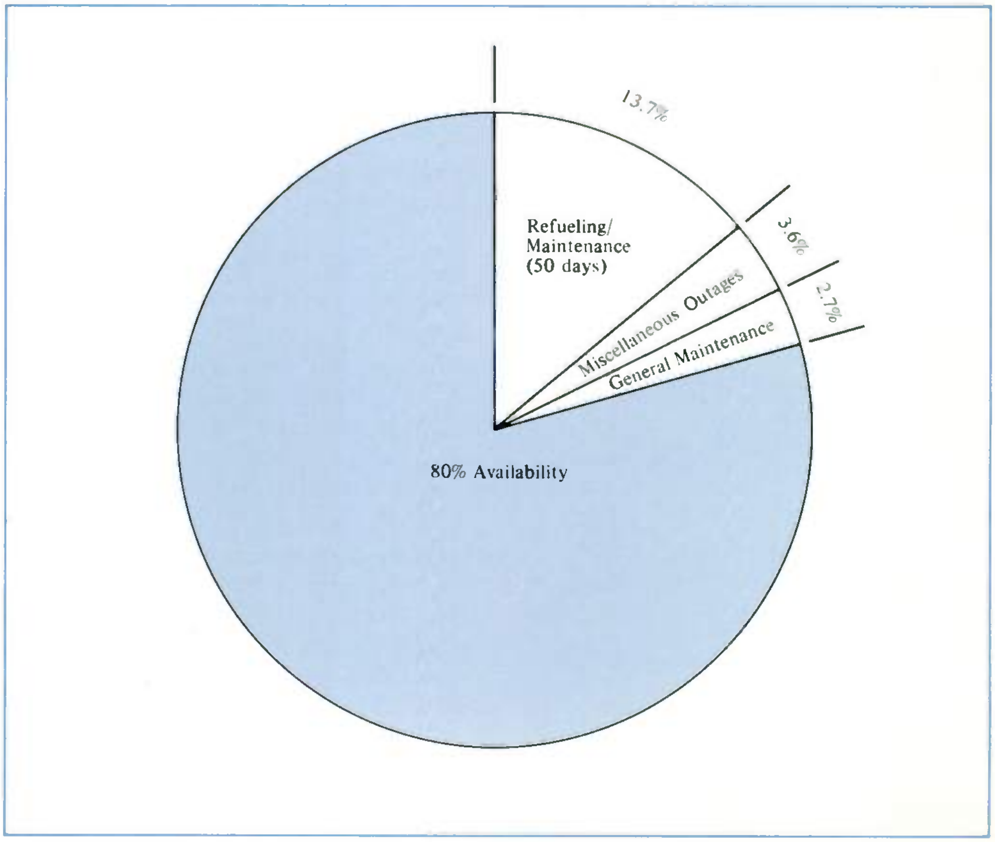
In evaluating the potential for improvement, analysis of refueling outage history indicated that, early in plant life, the annual refueling and maintenance outage has been predominantly maintenance. Refueling has been performed in parallel with maintenance but has required less time than maintenance activity. The average duration of these maintenance/refueling outages has been in excess of 50 days (Fig. 1).

However, after the nuclear plant passes through the early operation stage, which is characterized by extended maintenance requirements and warranty inspections, maintenance requirements decrease while fueling requirements remain constant. Eventually, maintenance requirements decrease to the point where refueling becomes the controlling factor in the duration of the total outage.

Several of today's operating reactors have exhibited this "refueling-limited" annual outage, which is about 34 days. Thus, it is for the "mature" nuclear plant that rapid refueling contributes to overall plant availability.

With the new rapid refueling system, the refueling activities now performed in 34 days can be compressed into seven days or less. Thus, the substitution of rapid refueling in future plants should lead to significant reductions in the overall refueling/maintenance outage.

Studies of both nuclear and fossil plants indicate that even if refueling time were



1—Average refueling, maintenance, and other outage records are summarized for three nuclear plants with Westinghouse reactors. These plants went into service in the 1969-71 period, and the operating statistics carry through 1972. The three plants had an average availability of about 80 percent.

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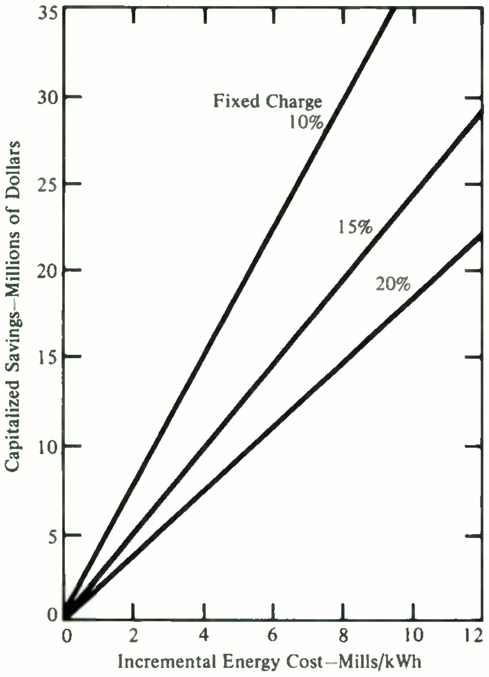
reduced to zero (as for a fossil plant) some maintenance activities would remain to control the minimum length of the outage period. Operating data for large fossil units (>600 MWe) show that average annual maintenance outages are approximately 20 days. Thus, the overall effect of faster refueling for a mature nuclear unit is to reduce the present refueling-limited annual outage of 34 days to a plant-maintenance-limited outage of about 20 days. This 14-day saving would provide an average annual availability improvement of about 4 percent.

The benefit of this availability improvement can be evaluated in terms of today's economic parameters. Current estimates of the cost to replace the generating capacity of a 1000- to 1300-MWe nuclear unit for one day vary, but a representative value is 10 mills/KWh ($250,000/day), which over a 14-day period amounts to $3.5 million. This cost of replacement power for a conventional nuclear plant is the source of the saving that would result from the rapid refueling unit because the annual refueling outage has been shortened by approximately 14 days. If this annual saving of $3.5 million is expressed as an equivalent capital investment evaluated at a typical utility fixed charge of 14 percent, it equals a capitalized saving of $25 million (Fig. 2). Furthermore, as the cost of replacement power (primarily fossil) increases, the economic benefits of maximizing nuclear unit availability will become even more commanding.



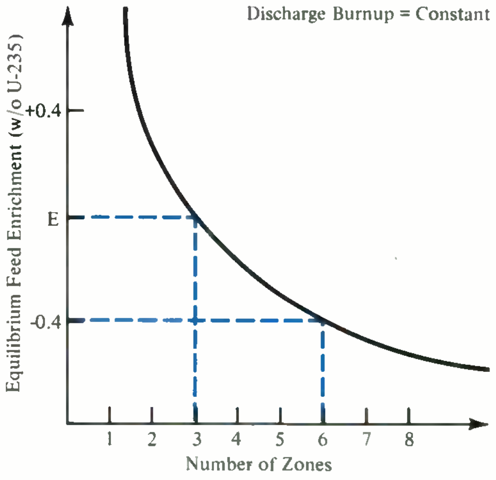
2—The savings that result from a four-percent improvement in availability are indicated. For example, if the cost of replacement energy is 10 mills/kWh, a four-percent improvement at a fixed-charge interest rate of 14 percent would provide approximately $25 million capitalized savings for a 1300-MWe plant.

Semiannual Refueling Capability

A second benefit of rapid refueling is the potential it provides to refuel more often than annually, the present practice. The early optimization studies indicated that constant ("on-line") refueling of nuclear units would be the ideal in terms of fuel economics, but the most expensive in terms of equipment capital investment. As a compromise between these two opposing factors, further study indicated that *semiannual* refueling has the potential to provide the optimum fuel cycle for a nuclear power plant.

The incentive for refueling twice a year rather than annually is the saving in fuel enrichment requirements. Assuming a constant discharge burnup, semiannual refueling could provide a 0.4 weight-percent reduction in uranium-235 feed enrichment for an annual fuel cycle saving of $2 million, or about 10 percent (Fig. 3). Expressed as a capitalized saving, that is more than $14 million.

With a refueling shutdown requirement of seven days or less, the rapid refueling system makes feasible a second short refueling outage six months after the major refueling/maintenance outage. And, in fact, studies of fossil- and nuclear-plant operating data indicate that this semiannual mode of operation would actually coincide with present power plant practices.



3—The fuel cost savings are shown for a semiannual fuel cycle. Conventional three-region cores are refueled annually (Equilibrium feed enrichment E); a six-region core refueled semiannually reduces enrichment requirements by about 0.4 weight percent.

In studying the plant outages of five operating Westinghouse PWR's encompassing 14 operating years, a significant semiannual trend is observed. In Fig. 4, each outage of more than three days' duration is plotted as a function of time. As would be expected, the majority of the planned refueling/maintenance outages occur either in the spring or fall to coincide with low-power-demand periods. Similarly, the majority of nonrefueling outages also occur during one of those low-power-demand periods. Generally, nuclear plants have been scheduled for annual maintenance plus refueling during one of the low-power-demand periods, and then, six months later, they are shut down again for a brief period for minor maintenance and inspection. With this existing semiannual tendency, it can be seen that inserting a seven-day refueling in parallel with the second maintenance shutdown would not impair the existing average annual availability of the unit. Thus, a semiannual fuel cycle could be made to coincide with existing maintenance practices—and the 4-percent availability improvement would still result from the shortened major outage.

Operational Flexibility

From an operational standpoint, a major benefit of rapid refueling is the options it provides in scheduling refueling shutdowns. Suitable fuel management schemes are now available to allow a switch from annual to semiannual cycles, and then a return to annual. The shortened refueling time allows refueling to be easily coordinated with maintenance activities and system load requirements as described above.

Looking to the future, as more and more nuclear units operate on a system, the flexibility of rapid refueling will become more important. Since each refueling and maintenance outage is shorter, more units can be refueled in series during a given low-power-demand period. This minimizes the impact of refueling outages on the overall power generating capability of the electrical system.

Manpower Requirements and Radiation Exposure

Another significant benefit that results from the time saved by reduced refueling operations is a reduction in refueling personnel man-hours by a factor of three. When these man-hour reductions are factored with the observed average radiation fields that occur during refueling, radiation exposure to refueling personnel is reduced by a factor of four (Table 1). Radiation exposure reduction becomes increasingly important to operating crews that must refuel several plants per year.

Rapid Refueling Design

The rapid refueling system is a combination of PWR design innovations and system improvements, which reduce the number of operator actions required in the refueling operation and minimize the number of components that must be handled.

The PWR design innovations encompass a combination of five key developments: a quick-release reactor head, called the Roto-Lok closure system; elimination of time-consuming electrical disconnects; a one-lift concept in which the missile shield, reactor vessel head, upper core-support structure, and rod cluster control assemblies are removed as a single unit; withdrawal of rod cluster control assemblies into the head and upper internals package where they are held withdrawn during refueling; and finally, improved fuel handling capability through refinements in the manipulator crane system. These five key developments reduce the number of handling operations by a factor of ten.

Roto-Lok Closure System

The new system used to close the reactor vessel to the reactor vessel head employs 36 closure studs modified with breech-block lugs (Roto-Lok) for attachment to the vessel. The lugs on the bottom end of the Roto-Lok stud are engaged or released from the reactor vessel flange by a 60-degree rotation (Fig. 5). Identical lugs on the top portion of the stud mate with the adapter of the hydraulic stud tensioner. The tensioner is locked to the stud by a 60-degree rotation of the tensioner adapter and hydraulic pressure is applied to stretch the stud; a closure nut is rotated as necessary to release or hold the tension on the stud; the hydraulic pressure is released and the tensioner is removed.

The Roto-Lok closure system provides a significant advantage over conventional threaded head-closure studs, which require excessive time to thread out of and into the reactor vessel flange. Also, the potential for handling problems is higher with threaded studs than with Roto-Lok studs.

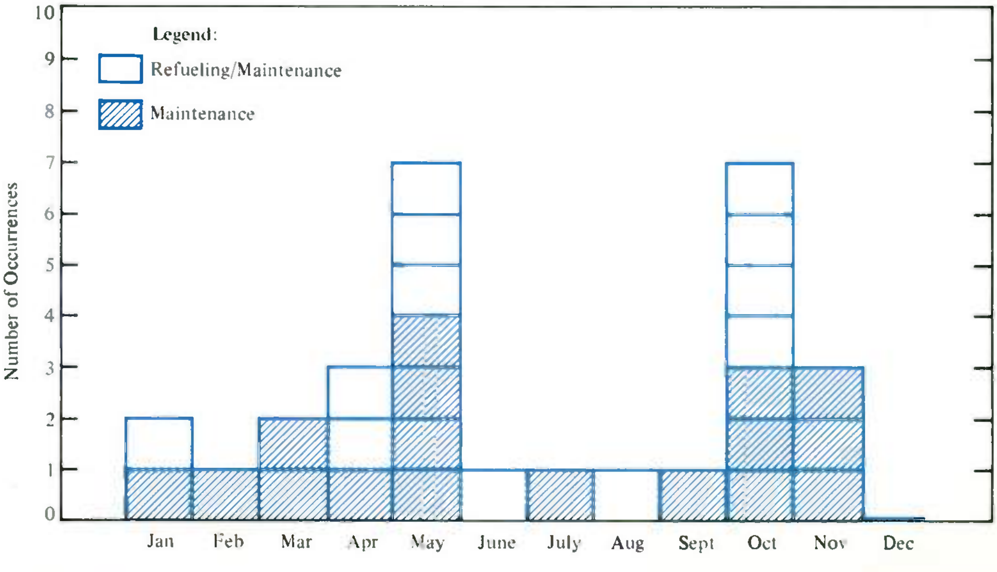
Cable Tray

A cable tray (Fig. 6) permits all electrical connections to remain connected when the reactor vessel head is removed, thereby eliminating the time spent in making and verifying electrical connections following refueling. The tray is a bridge-type structure, approximately 36 feet long by 8 feet wide, spanning from the cavity wall to the head cooling shroud. One end of the cable tray is supported by a hinged connection to the head shroud and the other end is supported by guide rollers that rest on the refueling canal wall.

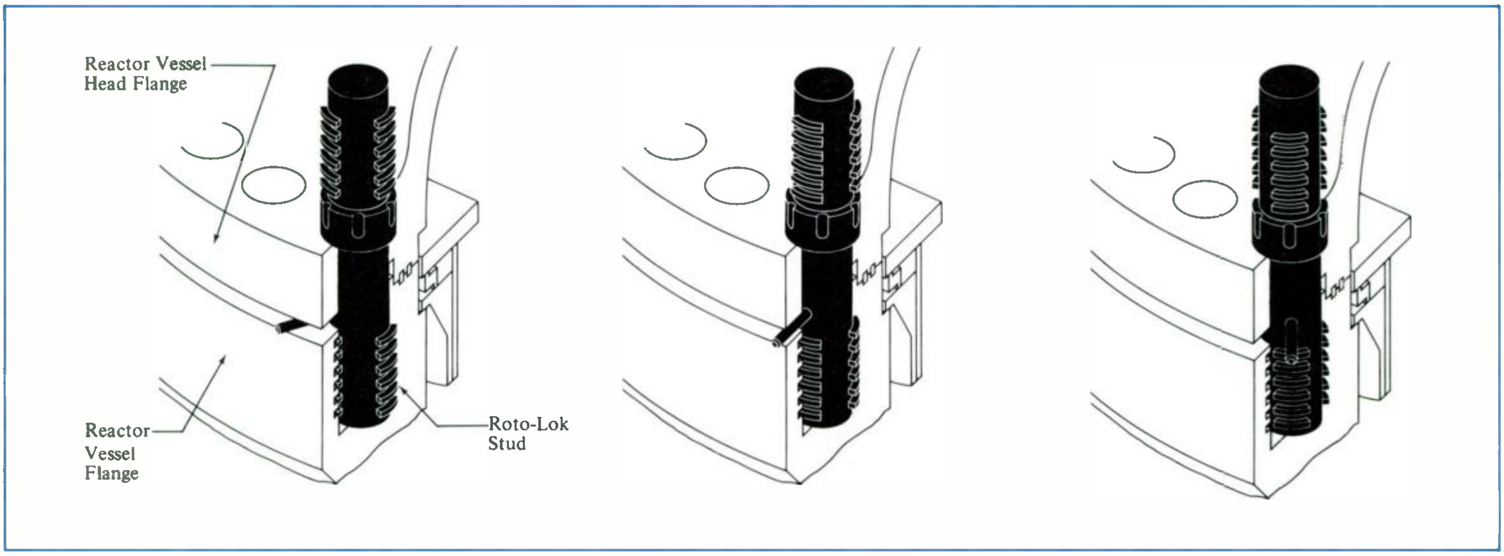
The cable tray carries power cables for the control rod drive mechanisms, signal cables for the rod position indicator system, and signal cables for in-core thermocouples. The cables in the cable tray are clamped at both ends of the tray and supported in spaces between by anchor brackets.

One-Lift Upper Package

The rapid refueling upper package combines the series of operations of missile



4—Outages of more than three days are summarized monthly for five PWR facilities with a total of 14 operating years of service. As indicated, 70 percent of the outages occurred during the normally low power demand periods of April-May and October-November.



5—The unique stud used in the Roto-Lok reactor vessel closure system has breechblock lugs rather than conventional threads. As indicated, the lugs can be engaged or disengaged by 60-degree rotation. The Roto-Lok system reduces the time required to open and close the reactor vessel by a factor of six compared to the conventional threaded stud.

shield removal, control-rod drive mechanism (CRDM) cooling duct removal, and upper core support structure removal into a single-lift operation. This is accomplished by connecting the missile shield to the head, connecting the upper core support structure to the head, and providing an integral CRDM cooling system (Fig. 7).

Missile Shield—The missile shield designed for the rapid refueling system is located at the top of the head shroud structure and is attached to the reactor closure head by four lifting rods. This design replaces the conventional concrete-and-steel shield that must be rolled back and out of the way prior to refueling.

The new missile shield design also serves functions in addition to missile protection. It is provided with large clearance holes to give lateral seismic support to the CRDM assemblies. The missile shield also serves as a spreader bar for the lifting rig, transmitting the load from the lifting rig through the lifting rods to the reactor vessel head.

Upper Core Support Structure-to-Head Arrangement—The closure head is connected to the upper core support structure by three lifting rods, which are attached by threading to the upper support plate and penetrate the closure head in adapters similar to those provided for the CRDM pressure housings.

This arrangement permits the head and upper core support structure to be removed and inserted as a unit. Under certain conditions, however, it might be necessary to disconnect the upper core support structure from the closure head for separate removal. This can be achieved by unthreading the lifting rods to permit the head, control-rod drive shafts, and upper core support structure to be removed in a conventional manner.

CRDM Cooling—To avoid the time required for disconnecting the CRDM cooling system, a forced-air cooling system is fitted into the head shroud structure. The cooling system consists of four fans mounted to the upper section of the cooling shroud. Ducts are located inside the cooling shroud to carry air from below the mechanisms.

CRDM/RCC Holding System

The rapid refueling system requires all rod cluster control (RCC) assemblies to be completely withdrawn and stored in the reactor upper core support structure guide tubes following boration of the reactor cooling system to the required refueling-shutdown boron concentration. This can be done by keeping one or both sets of magnet gripper coils energized to maintain positive engagement of both moveable gripper and stationary gripper latches with the drive rod.[1] However, since failure or interruption of electrical power to both coils would permit dropping of the RCC assemblies, a backup holdout device (or fail-safe lock) is provided on the full-length CRDM's (part-length CRDM's do not require the holdout device because their design prevents them from being released on loss of power).

6—This sequence of simplified diagrams illustrates the single-lift concept for removing the missile shield, reactor head, and upper internals. A cable tray permits electrical connections to remain connected.

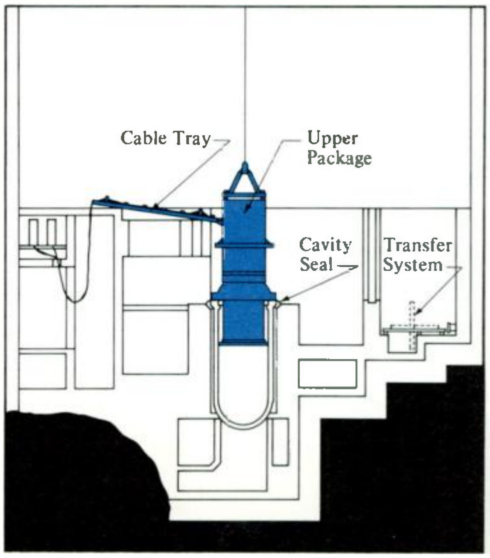


Table 1—Radiation Exposure Reduction with Rapid Refueling

Operation	*Average* Radiation Field (mrem/hr)*	*Man-Rem*	
		Conventional Refueling	*Rapid Refueling*
Missile Shield	24	0.4	0
Reactor Vessel Head Connections	20	4.6	0
Cavity Seal Ring	50	0.8	0
Reactor Vessel Stud Work	80	10.2	3.8
Guide Studs and Stud Hole Plugs	80	1.3	0.6
Reactor Vessel Head Lift and Cavity Fill/Drain	15	1.1	0.4
CRDM Drive Shafts	15	0.7	0
Upper Internals Lift	15	0.7	0
Fuel Shuffle	15	12.0	3.6
Total		31.8	8.4†

*Average for eight refuelings.
†Net reduction in operator exposure = 24 man-rem.

The backup holdout device is completely isolated electrically from the magnet gripper coils during normal plant operation and cannot be operated at reactor coolant system temperatures above 400 degrees F. When the holdout device is energized, it raises a latchbar into position behind the stationary gripper latch arms to hold them engaged. The mechanical latch that results no longer requires electrical power.

Manipulator Crane

Two modifications to the manipulator crane have improved the system's fuel-handling speed while retaining built-in safety and reliability:

1) A servo control system for bridge and trolley position control, referenced to the grid pattern of the core, permits pushbutton control to be used to automatically position the hoist over a fuel-assembly position.

2) A two-camera television system has been incorporated which permits viewing of all fuel positions. The monitor is connected to a video tape recorder for recording fuel assembly inspections and verifying core configuration.

Containment Features

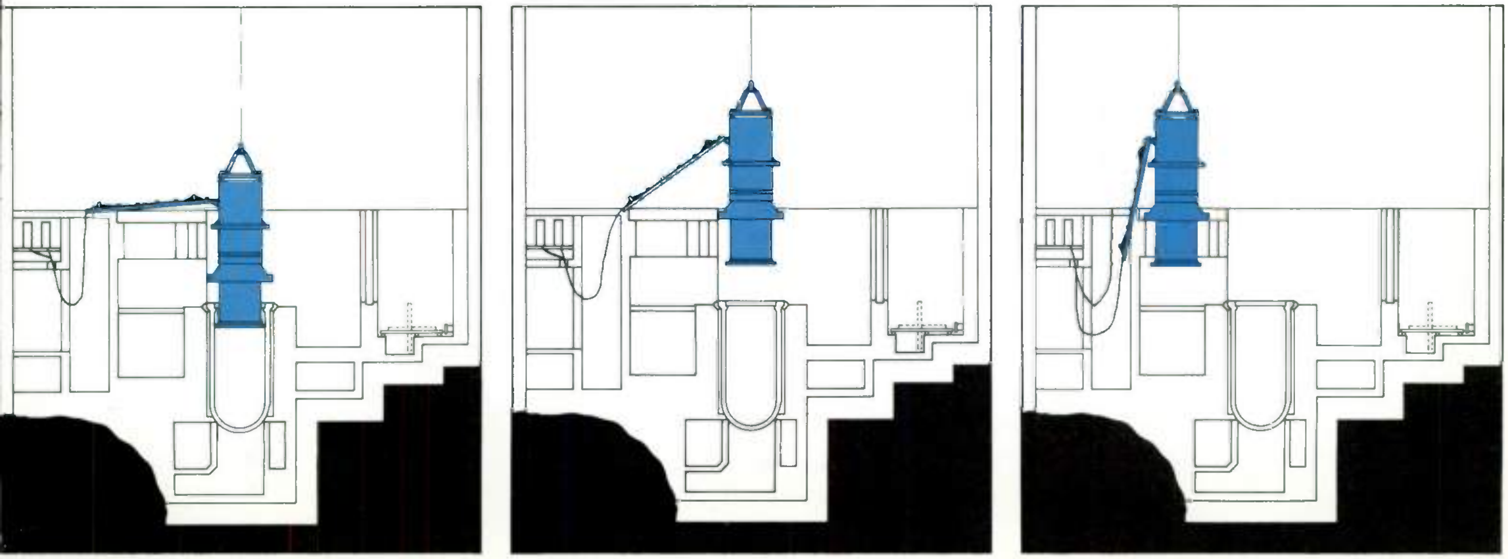
The rapid refueling design innovations also require several modifications in the refueling containment (Figs. 6 and 8), as compared with a conventional four-loop containment. First, the refueling cavity incorporates two independent areas: the main refueling cavity containing the vessel, head, and upper core support structure storage area and storage area for the lower core barrel; and the in-containment spent-fuel storage and fuel-transfer area. These two sections can be segregated by a bulkhead-type gate to permit either the main cavity or the transfer area to be filled or drained independently of the other.

Second, the use of the cable tray requires two changes in containment layout; a layup area is provided at the end of the cavity with support for the cable tray on the cavity wall, and an instrument room is provided for a common termination of cables.

Third, the cavity concrete-to-vessel seal is now a permanent quarter-circular metal seal. It removes the present necessity for testing and/or replacing seal O-rings at refueling and the sealing and raising of the seal plate.

Fourth, the out-of-core neutron detectors are bottom mounted to permit work on the detectors during refueling. Furthermore, should a detector fail during refueling, there is no need to drain the cavity to change the detector because it can be changed from below.

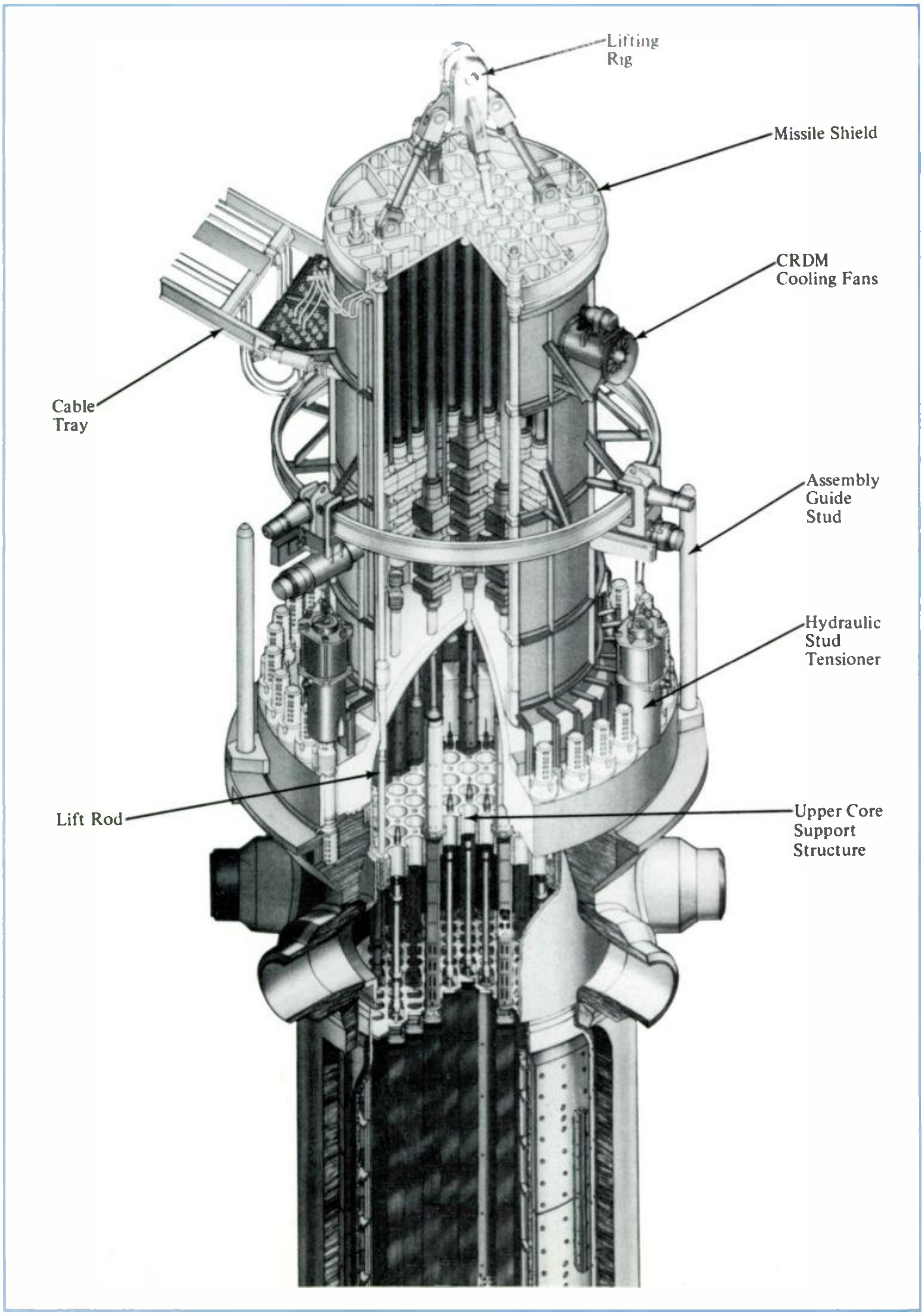
And finally, the storage area for the upper package is a circular segment of approximately 210 degrees to provide uniform head support. A keyhole opening is



cut out below the head support ledge to permit the upper core support structure to be placed in storage when it has been separated from the reactor vessel head.

Fluid System Design

More than just changing mechanical hardware is required to reduce refueling outage time. The time presently required for cleaning up the fission products in the reactor coolant system (RCS) when the fission product activity is above normal would make it difficult to achieve a seven-day refueling outage. Therefore, the RCS cleanup capabilities have been increased to minimize the impact of cleanup on the rapid refueling schedule.



7—(Left) *Cutaway drawing illustrates the one-lift upper package with cable tray attached.*

Performance requirements for the RCS cleanup system have been established for the design boundaries of contamination level: when the RCS is clean (no significant radionuclides), the cleanup system will permit commencing operations to open the reactor vessel 12 hours after shutdown; when there is the maximum design value of one percent defective fuel, the cleanup system will permit the containment to be opened to atmosphere 24 hours after the RCS is depressurized (approximately 32 hours after shutdown).

Chemical and Volume Control Systems—To provide 32-hour cleanup for the hypothetical one-percent defective fuel case, the flow capacity of the chemical and volume control system (CVCS) has been increased a minimum of 50 percent. The mixed-bed and cation-bed demineralizer's capacity has also been increased by 50 percent over the existing system.

Another factor in the cleanup of the RCS is the burst of radionuclides that occurs following depressurization of the RCS as a result of the fission gasses escaping through the cladding due to the internal fuel rod pressure. This activity must be handled by the cleanup system at low RCS pressure. When the RCS is at this low pressure, cleanup flow through the letdown orifices is reduced, which could extend the required cleanup time. Therefore, the rapid refueling design has a cross tie from the residual heat removal system to the CVCS, with a low-head 400-gpm pump in the cross tie. The pump provides the head required to move more fluid from the residual heat removal system through the demineralizing units and back to the RCS so that high cleanup flows can be maintained throughout all phases of the refueling process.

Waste Gas—Studies conducted on operating plants reveal that when there is a significant amount of radionuclide activity

8—(Right) *The containment arrangement for the rapid-refueling system accommodates the equipment innovations.*

in the reactor coolant system, the reactor vessel head cavity upon depressurization fills with radioactive gasses. The head cannot be lifted until those gasses have been removed. Therefore, provisions have been made in the rapid refueling design to use the head as the degassing vessel. A three-inch penetration on the reactor-vessel head connects the RCS with a vacuum pump in the waste gas system. (The line between the head and the vacuum pump runs on the cable tray so that it does not have to be connected and disconnected during refueling.) The head degassing system extracts the entrapped gasses for storage in decay tanks.[2]

Maintenance Programs Ready

A complete planned maintenance program has been prepared for the nuclear steam supply system to accommodate rapid refueling with semiannual outages. This maintenance plan was prepared to illustrate the potential availability gain possible with rapid refueling. In addition to the planning effort, a program of equipment maintainability analysis was conducted to improve components and thereby increase maintenance schedule "slack" time. This will allow for unpredictable delays that could not be identified in the planned maintenance program.

A similar maintainability analysis program has been conducted with the Westinghouse Steam Turbine Division. This work has resulted in improvements to the nuclear steam turbine design to accommodate the shorter outage schedules possible with rapid refueling.

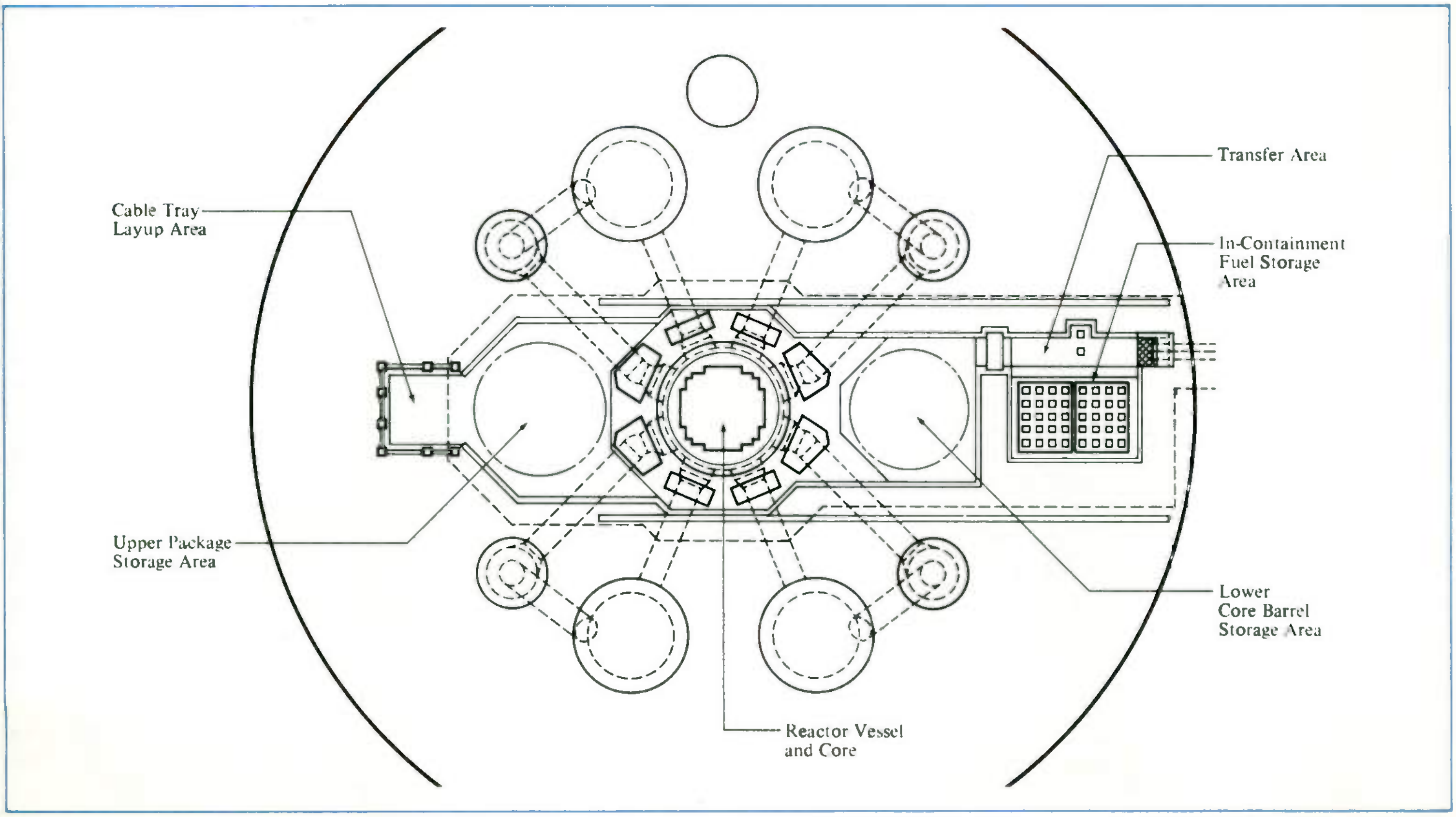
Current Status

Over the past four years, the Westinghouse Rapid Refueling System has progressed from an optimization program through a development project to the engineered system that is now being incorporated fully into plant designs. During its development, numerous utility operating groups and consulting engineering firms were solicited for suggestions that could contribute to improved design features and capabilities. Detail testing programs, design reviews, and conceptual designs have been extensively documented. The rapid refueling system is presently being incorporated into Westinghouse PWR's of several sizes. This Rapid Refueling System is part of the base design for the new 3817-MWt reactor. Both the 3425-MWt and the new 3817-MWt reactors have been ordered with the rapid refueling system.

REFERENCES:

[1] F. T. Thompson, "Solid-State Rod Control System for Pressurized Water Reactors," *Westinghouse ENGINEER*, March 1971, pp. 51-9.

[2] H. J. von Hollen and W. A. Webb, "New PWR Nuclear Power Plant Systems Reduce Radioactive Releases," *Westinghouse ENGINEER*, September 1971, pp. 130-4.



Technology in Progress

Fluid Systems Lab Tests Components for Wet-Dry Cooling Towers

When a conventional or nuclear power plant is being designed, ecologically acceptable methods must be found for dissipating the heat extracted from steam as it is condensed after passing through the turbine. One solution is use of a cooling tower, which prevents overheating the natural body of water that supplies the cooling water.

In the commonly used wet cooling tower, the water to be cooled is sprayed down through the tower so that it splashes over a matrix of slats called "fill." A draft of air drawn through the tower cools the cascading water, partly by convection and partly by evaporation.

Air leaving the top of a wet tower is saturated with water, and if it contacts cool air it can produce an undesirable cloud ("plume") or even fallout of water, ice, or snow. A solution to that problem is use of a wet-dry cooling tower, which consists partly of the conventional wet configuration and partly of dry finned-tube heat exchangers. The total flow of water can be divided between the two parts in the desired proportions to suit atmospheric conditions. In the summer, for example, most of the flow can go through the wet section without producing a cloud; in the winter, a greater proportion is sent through the dry portion to avoid saturating the air leaving the tower.

To evaluate the components that go into wet-dry cooling towers made by the Westinghouse Power Cooling Systems Department, a cooling tower test facility has been built by the Fluid Systems Laboratory at West Lafayette, Indiana. (The Fluid Systems Laboratory is part of the corporation's central Research Laboratories.)

The facility duplicates conditions in a section of a full-size tower of the cross-flow configuration, in which air enters horizontally at the sides, passes through the fill and drift eliminators, and then turns to flow upward through the fan stack. It is used mainly to examine the evaporative heat and mass transfer processes occurring in wet cooling tower fills, because those processes are more complex than dry heat exchange and thus less amenable to prediction without laboratory evaluation. However, it is also suitable for testing dry heat exchangers.

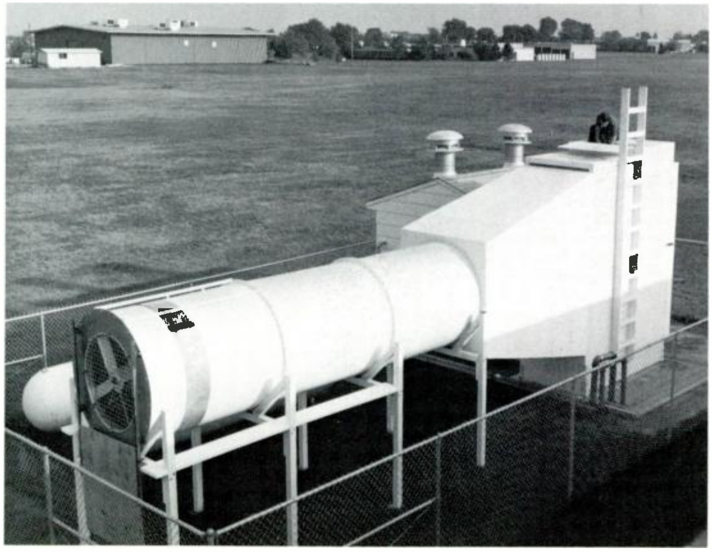
Thermocouples attached to the fill in the test facility measure the distribution of water temperature under different combinations of air flow and water flow. Hot-water flows of up to 10,000 pounds per hour per square foot can be supplied. Two water heaters each provide 1.25 million Btu per hour. The draft system can provide air velocities of up to 11 feet per second through the fill.

The facility has been used to determine the heat and mass transfer effectiveness of prototype fill slats with various water and air flows and temperatures. Temperature and flow data derived from the tests have been analyzed to determine heat and mass transfer coefficients, which, in turn, have been correlated to provide empirical relationships between heat and mass transfer, water loading, air loading, and other experimental parameters. Data extracted from the tests provides a sound technological basis for design of full-scale Westinghouse cooling towers.

The facility has also been used to test the containment effectiveness of prototype air inlet louvers and to evaluate the separation efficiency and pressure losses of a new drift eliminator design. Future testing will be oriented toward optimizing the geometries of fill slats and drift eliminators to provide the desired functions at minimum overall cost. Additional facilities at the Fluid Systems Laboratory provide for the testing of water distributor nozzles and for design studies of large axial fans and fan stacks.

Breakwater for Floating Nuclear Plants Being Tested in Model Basin

Extensive tests to determine the effects of wave action and ship collision on a scale model of a breakwater for floating nuclear power plants are being conducted as a step to assure the safety of such plants. The testing is being done by Public Service Electric and Gas Company (PSE&G) of New Jersey in the coastal and oceano-



(Left)—*The cooling-tower test facility includes the large fan at left that draws air through the cooling tower at right. The fill space (beneath the man) measures 4 by 4 by 10 feet.*

(Right)—*The basin used to test a scale model of a breakwater enclosing two floating nuclear plants is 95 feet wide by 125 feet long. At the far end is a wave generator that can produce wave action from a slight ripple to extreme storm conditions. A beach of crushed stone along the other sides prevents reflection of waves.*

(Far Right)—*Instrumentation leads are supported above the model. They collect data from measuring devices in and around the model and are connected to equipment that records wave agitation, hull motion and pressure, mooring forces, and wave heights.*

graphic engineering laboratory at the University of Florida's Gainesville campus.

The model simulates the Atlantic Generating Station planned for a site 2.8 miles off Little Egg Harbor, New Jersey. PSE&G has ordered two floating nuclear plants for the station from Offshore Power Systems, a joint enterprise of Westinghouse and Tenneco.*

The model, built on a scale of 1 to 64, was carefully constructed to represent as closely as possible all aspects of the New Jersey site, including the depth of the sea. The breakwater was erected with a base of caissons filled with sand and rock and covered by thousands of "dolosse"—simulated cast-concrete blocks of specific shapes. The dolosse are of three scale sizes representing 11-, 40-, and 62-ton structures.

The model of the plants and breakwater is built on a turntable to allow tests to be made at different wave attack angles. The initial orientation was at a 90-degree angle, which allowed the waves to strike the breakwater at its entrance. At this angle, the wave action inside the enclosure was at its maximum force, and the plants' hulls were tested for heave, surge, sway, yaw, roll, and pitch motions. In continuing tests, the model is being rotated to receive wave action at 60-, 135-, and 0-degree angles. At each angle, the breakwater is attacked by waves up to a scale height of 43 feet, the highest wave that could be generated by a hurricane at the proposed location off the New Jersey coast.

In the initial tests, the breakwater readily absorbed the energy of the peak storm waves. Only harmless spray found its way into the breakwater basin. Even the waves striking directly into the opening were so reduced that they caused the plant models to pitch or roll no more than three degrees.

To test the effect of a large ship crashing into the breakwater, a scale model supertanker was built; it represents a 326,000-ton vessel 1150 feet in length. A propulsion system using drop weights can crash the model at about 15 knots into the breakwater, after which the damage to the breakwater and the penetration of the ship are measured. The first tests have shown only minor damage to the placement of dolosse, with no possibility of the breakwater being breached.

Alternative Investments Evaluated by New Computer Program

Economic evaluation of alternative capital investment projects is facilitated by a computer program developed by the Advanced Systems Technology group in Westinghouse Power Systems Planning. The program calculates and tabulates annual revenue requirements associated with a proposed capital investment in generating plants or electrical equipment. Those revenue requirements consist of the cost of capital, depreciation, taxes, operating and maintenance expenses, and so on.

For each alternative project, the program outputs the expected minimum annual revenue needs on the basis of the retirement characteristics of the equipment and the present worth of the revenue requirements. In addition, if requested, the program calculates the expected effect of the project on earnings per share.

Input requirements are kept to a minimum by relying on the computer to calculate such values as financial equivalencies, retirement statistics, and levelized depreciation and tax rates. The corporate data necessary for a typical run consists of the cost of capital, accounting method used, book and tax depreciation methods, investment tax credit, tax rates, the portion of debt in the capital structure, and the interest on debt. For each investment proposal, the typical input required is the capital invested, plant replacement policy, growth rate, average life, retirement dispersion, salvage value, operating and maintenance expenses, and other general expenses.

Ultrasonic Cleaning Helps Improve Computer Disc Memories

Close dimensional tolerances are required between the individual magnetic wafers that are stacked into rotating disc packs

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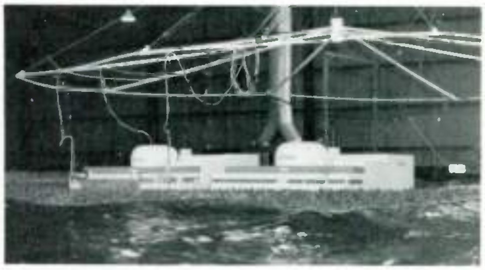
*Alan R. Collier and Roger C. Nichols, "Floating Nuclear Power Plants for Offshore Siting," *Westinghouse ENGINEER*, Nov. 1972, pp. 162-9.



for computer memories, and clearances also are critical between the packs and the read/write heads that travel above and below them on a cushion of air. Consequently, even minute imperfections or contaminants on the wafer surfaces can impair the fidelity of data storage and shorten the useful lifetime of the assembled packs.

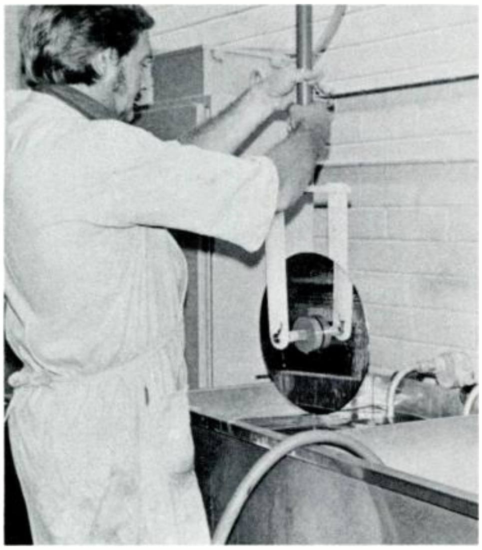
To remove dirt and prevent recontamination during the washing process, Sperry Univac, a division of Sperry Rand Corporation, cleans its wafers with an ultrasonic cleaning and solvent drying system supplied by the Westinghouse Industrial Equipment Division. The wafers begin as aluminum discs 14 inches in diameter and ⅛ inch thick. After heat treatment for dimensional stability and diamond machining to achieve flat smooth surfaces, the wafers are plated to a thickness of 0.003 inch on each side with nickel and then lapped smooth.

Before the ultrasonic cleaning equipment was installed, the plated wafers were hand scrubbed in an alkaline bath, rinsed in water, and air dried. They were then plated with 0.004 inch of gold, 0.004 inch of nickel-cobalt, and 0.005 inch of rhodium. They were hand scrubbed again, rinsed, and dried before being assembled into ten-wafer disc packs. Both cycles of wash, rinse, and dry were tedious and time consuming. More important, they did not remove destructive fingerprint oils, and the surfaces were further marred by water spots that left mineral deposits.

The new equipment solved the problem. After the nickel plating and the gold, nickel-cobalt, and rhodium plating, the wafers are now cleaned in a two-tank six-kW ultrasonic unit. Wafers are lowered individually into a cleaning solution. There, bubbles created by high-frequency agitation collect on their surfaces; when the bubbles burst, cleaning solution rushes in to fill the voids and, in the process, tears dirt off the surfaces of the wafers.

Following rinsing, the wafers are dried in a three-tank system containing Freon solvents. In the first tank, the wafers are dipped in Freon T-DA 35 drying solvent to displace all water. The water floats to the surface of the solvent and is mechanically skimmed off so that dried wafers can be removed from the tank without passing through a layer of water. The wafers are then immersed in two tanks of freshly distilled Freon TF to remove any residual drying agent. As they are lifted from the liquid in the third tank, they are sprayed with Freon TF. The result is absolutely dry and spot-free wafers that are ready for assembly.

Besides producing cleaner surfaces, the process is significantly faster than the hand brushing and air drying method. It takes about two minutes for cleaning and four minutes for drying.



(Top)—*Wafers for disc memories are cleaned, before plating, in an alkaline bath in this two-station six-kW ultrasonic unit at Sperry Univac's Bristol, Tennessee, plant.*

(Bottom)—*The cleaned wafers are rinsed and dried with Freon solvents to insure that all contaminants and water spots are eliminated.*

Mini-Power Centers Facilitate Addition of New Distribution Circuits

Traditionally, when an industrial plant needs new distribution circuits, the plant electrical engineer works out specifications, provides installation instructions, and orders components such as a transformer, junction box, conduit, primary disconnect or breaker, and panelboard. Besides the cost of the engineering and assembly time, that method of providing a distribution center risks delays caused by engineer work loads, late delivery of key components, or wiring errors during assembly. A simpler method is use of the packaged Green Line Mini-Power Center made by the Westinghouse Specialty Transformer Division.

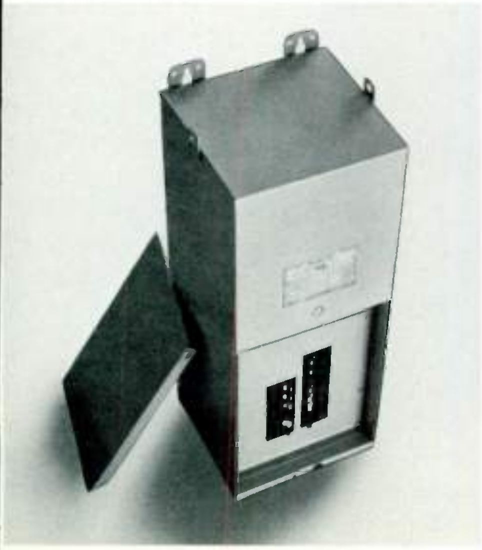
Besides simplifying the addition of branch circuits, the Mini-Power Center eliminates coordination problems in ordering because only the kVA size and the secondary breaker ratings need be specified. It also greatly reduces installation cost by saving time in installation.

To add new 120- or 240-volt distribution circuits to a plant's 480-volt feeder system, the feeder is simply tapped and a line is run to the Mini-Power Center, which contains in a single indoor/outdoor enclosure the necessary transformer, primary breaker, panelboard, and secondary breakers. Mini-Power Centers are available in ratings of 5, 10, 15, and 25 kVA, single phase, and they can provide up to 20 branch circuits of 120 volts, 10 circuits of 240 volts, or a combination of 120- and 240-volt circuits.

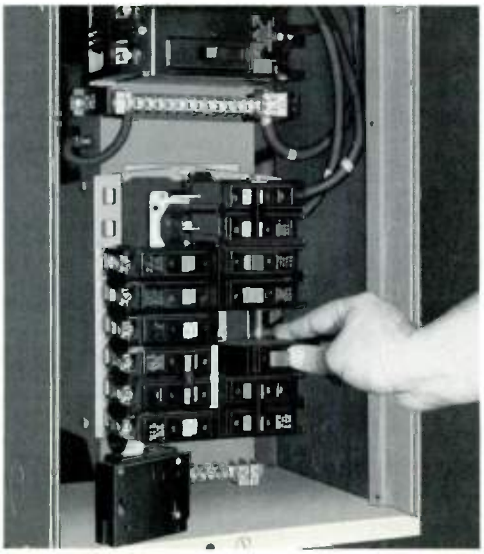
The Mini-Power Center is shipped with a two-pole main secondary breaker that protects the entire panelboard section. For each circuit, the user plugs in an individual secondary breaker of the ampere rating required by that circuit. Either Westingouse Quicklag P or Bryant BR breakers an be used, in single- or two-pole type. he standard secondary breakers have nterrupting capability of 5000 amperes, nd special breakers are available with 0,000-ampere capability. Branch circuits an be added or changed to meet new reuirements by simply plugging in the ppropriate breaker and connecting the ine.

The Mini-Power Center can be mounted n walls, columns, panels, or other suraces. Its Green Line dry-type transformer s sealed by an insulation system of baked poxy resin and sand that forms a solid lock around the core and coil. Thus, the Mini-Power Center can be installed in irtually any atmospheric or temperature nvironment. Heat is removed by conducion, eliminating the need for air flow.

All live parts are completely enclosed, nd the hinged access door can be padocked. The unit is listed by Underwriters' Laboratories, Inc.



Below)—*Mini-Power Center takes the place of a eparate transformer, primary breaker, and paneloard when new circuits need to be added to an ndustrial or commercial distribution system. The esult is considerable savings in planning and installaion costs.*



Right)—*The secondary breakers for the branch ircuits are of plug-in type for easy replacement when different ratings are needed to meet changing equirements of the circuits.*

Arizona's Navajo Transmission Project Nears Completion

All major installation and construction work has been completed on three 500-kV switching stations and a 345-kV series capacitor bank as part of the Navajo Project southern transmission system between Page and Phoenix, Arizona. Arizona Public Service Company has acted as project manager for the system on behalf of five other utilities and government agencies involved in building and operating the 2310-MW Navajo power plant near Page and the associated transmission system. The other participants are the Salt River Project, Tucson Gas and Electric Company, Nevada Power Company, the City of Los Angeles Department of Water and Power, and the U. S. Bureau of Reclamation.

The switching stations are the first such installations in the United States for which a single supplier handled equipment installation and station construction. Major equipment supplied by Westinghouse divisions included transformers, shunt reactors, series capacitors, power circuit breakers, part of the relay systems, and associated apparatus. The company's Special Services Division performed all on-site switching-station construction work and equipment installation, and it also handled all subcontracts.

The transmission portion of the Navajo Project begins with a major switching station at the power plant near Page. This station includes ten 500-kV power circuit breakers, associated interconnections and control, and the terminal series capacitor and shunt reactor compensation for three transmission lines, two of which stretch south and the third toward Los Angeles.

One of the southern lines goes 255 miles directly to the Westwing switching station near Phoenix; the other goes through the Moenkopi switching station near Cameron, Arizona, about 75 miles south of Page, before continuing to Westwing. The Moenkopi station existed before the start of the Navajo Project as a series and shunt compensation point on another transmission line. It was expanded for a breaker-and-a-half design with a four-breaker ring installed for initial operation. Series-capacitor and shunt-reactor compensation were added to the western line as well as the lines between the Navajo and Moenkopi, and the Moenkopi and Westwing, switching stations.

The largest switching station is Westwing. (See back cover.) Situated on a 160-acre tract, it contains a 500-kV switchyard, a 230-kV substation, and a 345-kV line termination. The 500-kV yard is a breaker-and-a-half design with series and shunt compensation for the two lines from the Navajo power plant, with two outgoing 500-to-230-kV step-down transformer banks and one 500-to-345-kV step-down transformer bank. The 230-kV yard has ten breakers in a breaker-and-a-half arrangement, while the 345-kV line termination is for a transmission line that Tucson Gas and Electric Company is constructing from its area of Arizona.

Additional switching-station equipment is being installed for new generating capacity at the Navajo power plant, scheduled for operation later this year and next year.

Products and Services

Coupling capacitor potential device, Type PCA-7, is designed specifically as a potential source to drive high-speed static relaying systems. It is available for voltages of 115 kV and above and has a transient response characteristic equivalent to that of a wound potential transformer for relaying applications. The device has 200-VA total burden capacity and is preadjusted to maintain one-percent accuracy within its burden capacity. It is available with optional carrier accessories, and its high capacitance extends carrier broad-band coupling above 345 kV. *Westinghouse Distribution Apparatus Division, P. O. Box 341, Bloomington, Indiana 47401.*

Solid-state reclosing relay, Type SRCU-2, is designed for high-speed automatic restoration of faulted transmission and subtransmission circuits. It is used in any reclosing application that requires synchronism-check, hot-line dead-bus, and hot-bus dead-line control. "Hot" and "dead" level detectors are adjustable from 3 to 120 volts and are independent of each other. Automatic reclosure is adjustable from one to three shots to lockout. An intermediate lockout setting holds final reclosure until bus and line are hot and synchronism exists. Indicator lights reveal reclosing relay action since the previous reset. Relay reset time can be from 3 to 60 seconds and is controlled by a dial on the front panel. An optional Logic II module contains a supervisory close function. The SRCU-2 operates on either 48 or 125 volts dc. *Westinghouse Relay-Instrument Division, 95 Orange Street, P. O. Box 606, Newark, New Jersey 07101.*

Solid-State Reclosing Relay

Water-cooled heat-sink jackets are now available for all Westinghouse power rectifiers and SCR's. The jackets are cast from solid copper, eliminating the cracks, voids, and leaks that are possible with brazed heat sinks. They are typically three to six times more efficient than air-cooled heat exchangers, and they can be used with oil coolant as well as water. They are available either alone or assembled with rectifiers or SCR's. R-C tabs are available as an option so that resistors, capacitors, and surge suppressors can be mounted directly across the semiconductor devices. *Westinghouse Semiconductor Division, Youngwood, Pennsylvania 15697.*

Packaged central air conditioners for commercial and residential applications now permit addition of slip-in electric resistance heaters. The new line, called the UD Packaged Electric Cooling/Heating System, also has a lower silhouette for easier concealment on roofs or in shrubbery. The 2- and 2½-ton units are 26½ inches high; 3- and 3½-ton units are 30½ inches high. Up to 19.2 kW of electric heating can be added to the 2- and 2½-ton units. The larger units can take up to 28.8 kW. The units are completely weather resistant and provide easy access for maintenance. *Westinghouse Central Residential Air Conditioning Division, Norman, Oklahoma 73069.*

"Thyristor Firing Circuits—Series, Parallel, and Sequential Operation" is the latest in the Tech Tips series on selection, application, use, and maintenance of power semiconductors and subsystems. The illustrated six-page publication discusses the performance problems commonly related to gating circuitry, many of which can be alleviated by a good gate signal from a common source. It then presents six common-gating circuits for sequential, series, or parallel firing of SCR's and explains the pros and cons of each design. *Westinghouse Semiconductor Division, Youngwood, Pennsylvania 15697.*

Electric water cooler, Model WFE 10RB is designed for use in potentially explosiv atmospheres. All electrical parts are contained in UL-listed vapor- and air-proo enclosures. Capacity is 10 gallons of 50 degree water per hour at inlet water temperature of 80 degrees and at 90-degre ambient—sufficient for servicing up to 12 people. The unit has a precooler that utilizes waste water to cool incoming wate for more efficient operation. It operates o 115 volts, 60 hertz. *Westinghouse Wate Cooler Department, Box 28188, Columbus Ohio 43228.*

Westinghouse International School for Environmental Management will meet July 14 to 27 on the campus of Colorado Stat University, Fort Collins, Colorado. Thi fifth annual school is organized as an educational course for managers and executives in the environmental field. It will hav as its theme "Environmental Managemen During the Energy Crisis—the Challenges the Solutions." The curriculum has bee broadened from previous years to includ such timely topics as need for power assessment, expedited environmental programs development of site banks, socioeconomi and human-impact analyses, and environmental technical specifications. Lecture will be supplemented with field trips, laboratory work, and case studies. As in the past, the school staff will consist of leadin authorities from industry, government, and academia. Enrollment is limited to 40 participants. *Dr. J. H. Wright, Director, Westinghouse Power Systems, Environmenta Systems Department, P. O. Box 355, Pittsburgh, Pennsylvania 15230 (telephone [412 256-7991 or 6279).*

bout the Authors

. A. Regotti graduated from Milwaukee School
f Engineering in 1951 with a BS degree in elec-
ical engineering. He joined Westinghouse on
e graduate student training program and went
work at the Switchgear Division. There he
ined the Switchboard Automatic Control
ction, which designed controls for synchronous
ndensers, carrier relaying for high-voltage
ansmission lines, and water-wheel generator
ations.

Regotti moved in 1959 to the Systems Engi-
eering Section, where he is presently Power
ystem Consultant. He is responsible for all of
e Division's fault studies and relay coordination
udies and, in addition, he assists industrial and
ectric-utility district engineers with such studies.
e lectures at the Industrial Relay Application
hool held annually by the Relay-Instrument
ivision, and he is Chairman of the Westinghouse
elay Protection Committee. He is also a member
f the Industrial and Commercial Power Systems
ommittee of the IEEE Industry Applications
ociety.

. W. Wargo earned his BS degree in electrical
gineering at Pennsylvania State University,
aduating in 1968. He joined Westinghouse and,
ter the graduate student training program,
ent to Industrial Projects Marketing as a power
stems engineer. That engineering group was
tegrated into the Industry Services Divisions
hen the latter were formed in 1971.

Wargo's work involves the study of industrial
ower distribution systems to insure continuity
f service and equipment protection. Those goals
e usually achieved by one or more of the follow-
g studies: short circuit, device coordination,
ad flow, motor starting, harmonic analysis,
d stability. All of them are computerized and
n accommodate the largest industrial distri-
ution systems.

T. C. Giras joined Westinghouse in 1961 at the former Computer Systems Division, where he worked on the early development of noninteracting boiler control and electrohydraulic control for extraction steam turbine systems. In early 1963, he was made responsible for development of the first all digital automatic dispatching system for electric utilities. He then worked on the application of concepts developed for the small extraction steam turbines to an analog electrohydraulic package for large steam turbines, and he later extended the concepts to the development of Digital Electro-Hydraulic (DEH) control. He has basic patents in all those areas.

Giras has also been responsible for the application of similar concepts to gas turbine controls and more recently to the PACE control system. He holds degrees in electronic engineering and in electrical and instrumentation engineering. He has published extensively in the area of total energy management for electric utilities, turbine controls, and boiler control applying both analog and digital technology. When the Westinghouse control divisions were realigned last year, Giras was made Manager, Gas Turbine Control Systems, Industry Systems Division.

Paul A. Berman graduated from the University of Pennsylvania with a BSME in 1953 and obtained his MSME there in 1956. He joined the Westinghouse Gas Turbine Division (now the Gas Turbine Systems Division) in 1953, where he worked first on cycle analysis and compressor and turbine design in the thermodynamics section. He then moved to the special project section and worked with systems involving nuclear gas turbines, marine gas turbines, and circulators for gas-cooled reactors.

Berman has also served in the Division's application engineering and product engineering section, contributing to the design of the COSAG marine gas-turbine plant, gas-turbine exhaust-heat boiler systems, and the 25-MW Econo-Pac gas-turbine generator package plant. He served as Supervisor of Value Engineering for two years and is presently Manager of Combined Systems Engineering, where he works on combined-cycle power systems such as the PACE plants described in this issue. He has five patents to his credit.

Harry N. Andrews graduated from the University of Pittsburgh (1952) with a BSME in Power Plant Engineering and then attended Chrysler Institute of Engineering for two years to obtain a Master's degree in Automotive Design. After a variety of assignments in automotive design at Chrysler Corporation, he joined the Westinghouse Atomic Power Division in late 1959 to begin a career in the design of nuclear reactors.

Andrews was appointed manager of a mechanical design and development group in 1964 and has since progressed through a variety of engineering management positions, all concerned with various phases of nuclear reactor design. He is presently Manager of Mechanical Equipment Engineering in the Pressurized Water Reactor Systems Division.

Gerald L. Deroy graduated from the University of Rhode Island in 1971 with a BS degree in Mechanical Engineering and is currently working toward an MS in Nuclear Science and Engineering at Carnegie-Mellon University. He joined Westinghouse on the graduate student training program in 1971, after which he was assigned to the Application Engineering group of Water Reactor Divisions Marketing. Deroy's responsibilities as an Application Engineer include performing preliminary design work for proposals to utility customers as well as technical support during negotiations. His current assignments include both technical and economic analysis of alternative refueling schemes, and matching systems performances with individual utility power systems characteristics and requirements.

C. Arthur Olmstead graduated from the South Dakota School of Mines and Technology with a BSME in 1961. While working for the Phillips Petroleum Company (1961-66), the Idaho Nuclear Corporation (1966-69), and the Westinghouse PWR Systems division, he participated in the NRTS Extension Program at the University of Idaho to earn his MS in Mechanical Engineering (1971).

His first assignment at Westinghouse as a Senior Quality Control Engineer was on various phases of plant quality assurance. In 1971, he was made a Senior Engineer in mechanical development and served as lead engineer in the development of the rapid refueling program.

Olmstead is presently a Principle Engineer working in New Products. He has lead responsibility for mechanical designs in the new 3817-MWt program.

Westinghouse Electric Corporation
Westinghouse Building
Gateway Center
Pittsburgh, Pennsylvania 15222

The new Navajo Project transmission system in Arizona includes the Westwing switching station, near Phoenix, where these photographs were taken. At right are the Westinghouse 500-kV SF_6 *power circuit breakers and accompanying current transformers. The view below, down the length of the 500-kV switchyard, shows four 500-to-230-kV step-down transformers in the center; the one on the left is a spare, while the other three make up the bank now in use. In the foreground are tertiary reactors and associated circuit breakers, and on the right is a 750-kVA station-service transformer. At bottom right is another view of the step-down transformers and the overhead transmission structural work. For more information about the Navajo Project, see page 63.*