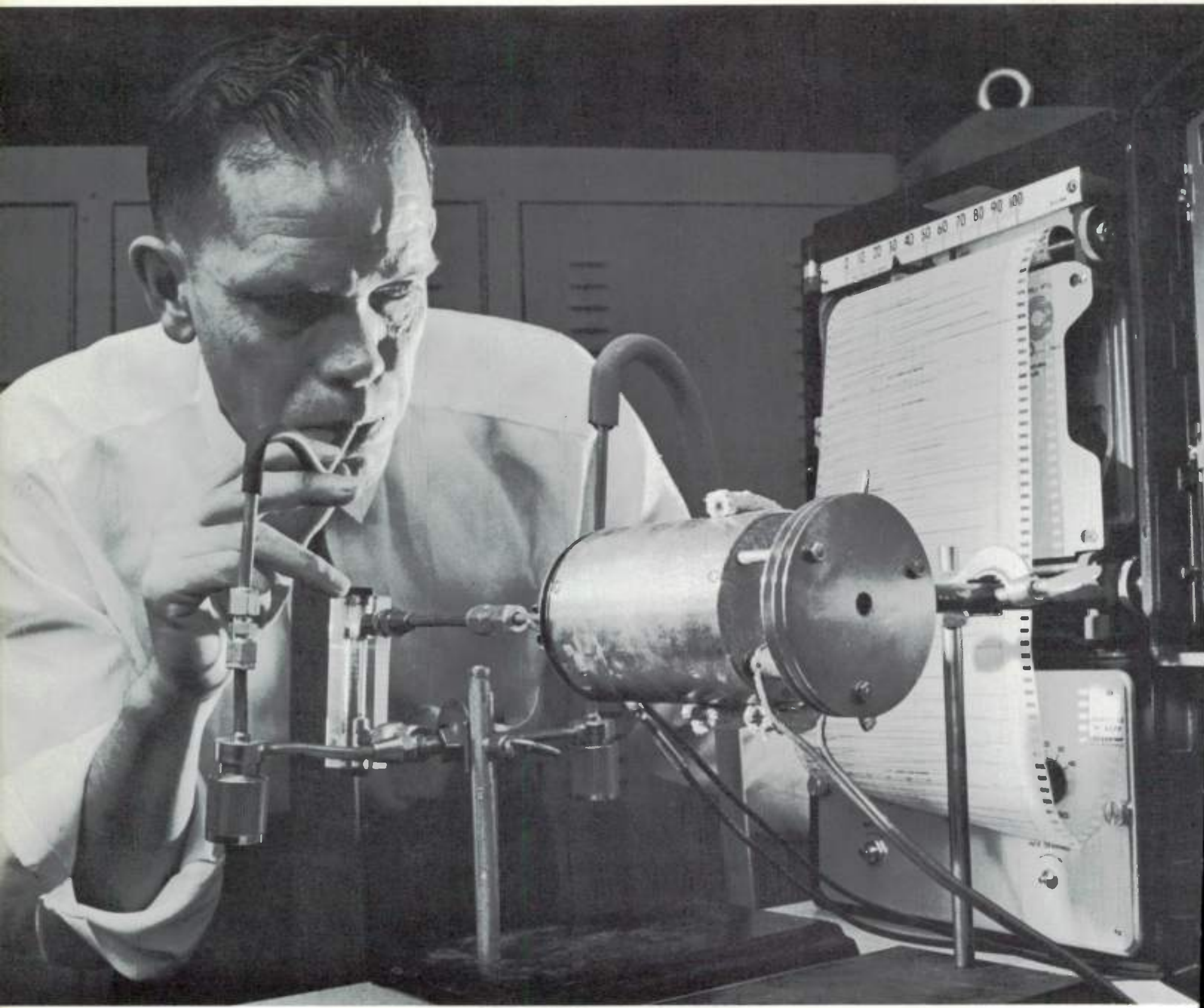
Westinghouse ENGINEER

MAY 1964



The oxygen detector being demonstrated here can measure as little as one part of oxygen gas per million. The detector (housed in the metal cylinder in the foreground) is essentially a fuel cell, and it reacts to oxygen that enters it by generating an electric voltage. This voltage is proportional to the amount of oxygen present, so it can be registered on the moving chart as oxygen content in parts per million. The demonstrator here is using the device to monitor the oxygen content of the air exhaled from his lungs.

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Cover Design: The Automatic Digital Dispatch and Processing System (ADDAPS) uses a digital computer to direct an analog generation control system. The digital computer calculates the economic dispatch for the system, and assigns load to each generator via a base load setter in the analog control loop for that generator. The dial of a base-load setter is featured in this month's cover design by Thomas Ruddy of Town Studios, Pittsburgh.

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ADDAPS . . .
Automatic Digital Dispatch and Processing System

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This economic dispatching system uses a digital computer to direct analog generation-control equipment, thus freeing computer capacity for additional tasks, such as energy interchange billing, energy accounting, and outage diagnosis. The combined digital-analog approach also provides analog control backup during periods of digital computer maintenance.

The Automatic Digital Dispatch and Processing System (ADDAPS) recently put into service by the Arizona Public Service Company is a combined digital-analog system controlling the Arizona Public Service and Salt River Power District pooled generation and transmission system. This digital-analog approach was chosen because it provided an excellent opportunity to use the digital computer for more than just economic power dispatch. By using the digital computer to *direct* an analog generation-control system, much of the digital computer capacity is freed for additional tasks. System operating engineers plan to use the capacity of the digital computer to provide four general functions: control and economic dispatch, scheduling and forecasting, network analysis studies, and data processing. The Prodac 580 digital computer with a strong priority system permits the computer to be time-shared for other jobs without in any way hindering the primary function of economic dispatch. Thus, the ADDAPS system opens up a whole area that is virtually untouched—on-line system operation by digital computer.

Need for Digital Computers

A variety of methods employing analog techniques have been used to control generation automatically during the past 20 years. The first systems merely compared system load requirements with system generation, and if an error existed, the control system altered generator output, without particular regard to economics, until a new system balance was attained. Later systems have taken generation costs into consideration, and some even have considered transmission penalty factors.

However, with analog systems, these various cost-curve data must be stored in resistor-diode networks. The break points and slope of each straight-line segment can be set but the dispatching system's ability to accommodate frequent change is limited. The computer can store cost data either as sets of straight-line segments or as sets of polynomial curves. Thus, as system capacities become larger and the potential savings of economic dispatch greater, the digital computer with its inherent flexibility becomes more and more desirable for handling the economic-dispatch routine. Careful programming enables the computer to quickly handle changes in fuel costs, transmission penalty factors, and other changing economic considerations, thereby insuring an optimum saving in the overall system cost of power generation and transmission.

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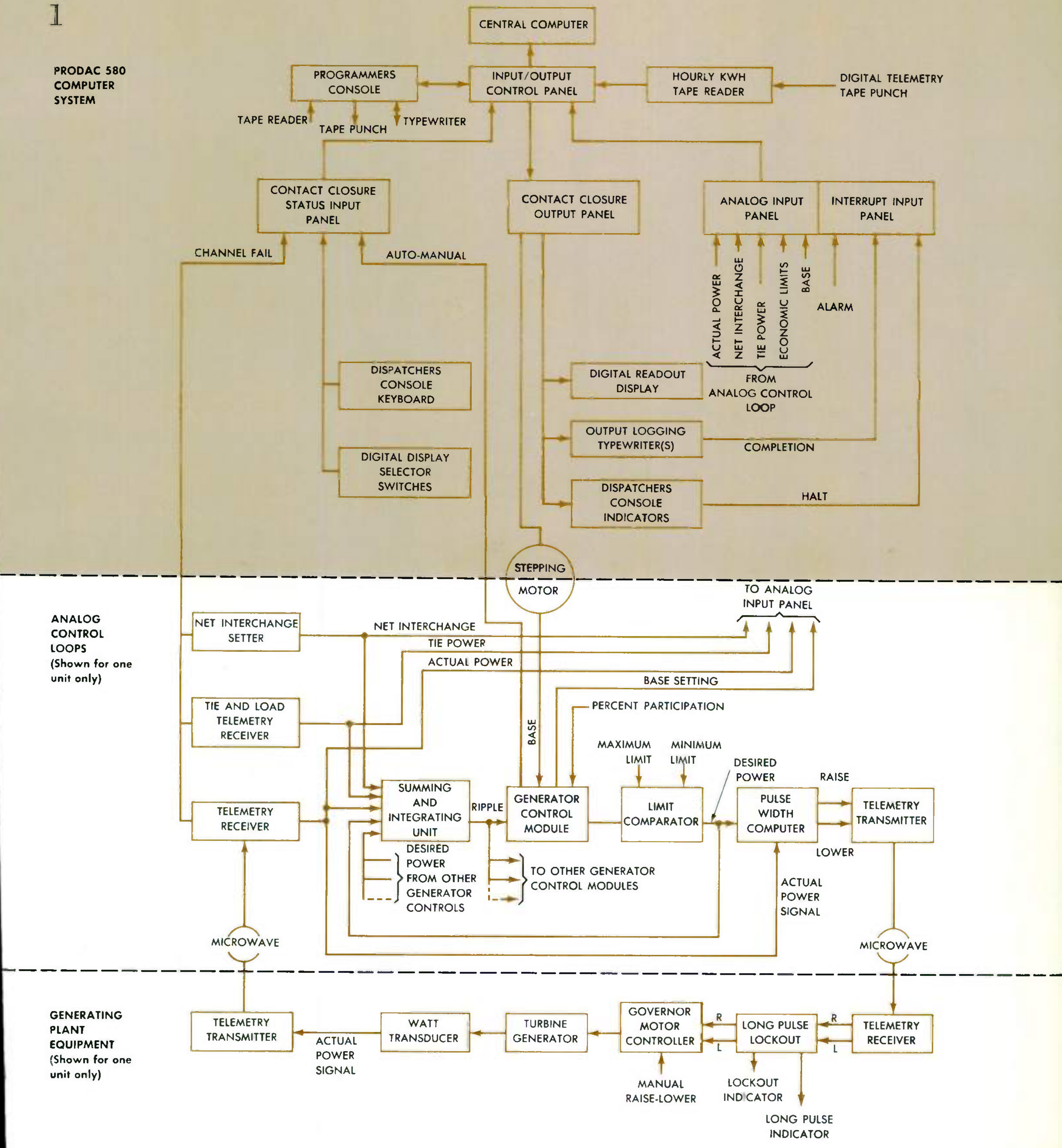
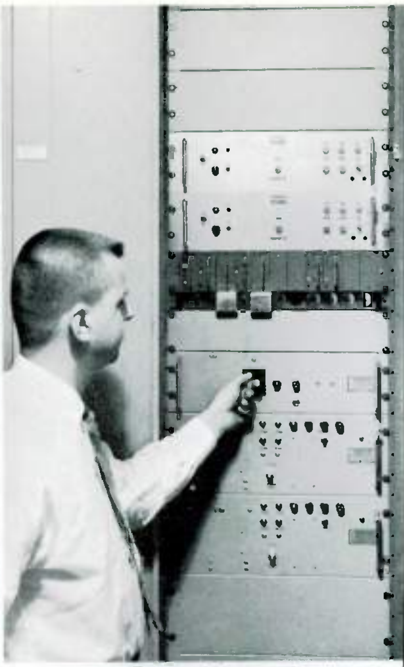
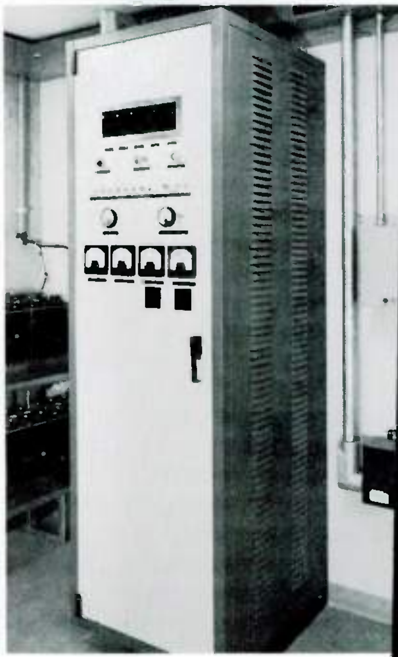


ADDAPS SYSTEM consists of a Prodac 580 computer system, which computes the base settings for the 14 generating units controlled. These base settings are forwarded to each of the 14 analog control loops that regulate generation for each unit.





DISPATCHER'S CONSOLE (top left) has been designed to provide for expansion of the power system to four times present generating capacity.

ADDAPS DIGITAL COMPUTER (lower left) and dispatch office analog equipment is located in the room in the foreground, and the dispatcher's console in the adjoining room. Separation facilitates the sharing of the digital computer between control and data processing.

GENERATING STATION EQUIPMENT (top right) includes telemetry equipment and a governor motor controller for each generator in the station.

EMERGENCY STANDBY POWER SUPPLY (lower right) rated at 7.5 kva provides power to all ADDAPS equipment at the pool dispatching center.

Furthermore, the increased real computing ability available in the modern digital computer permits fresh approaches to the economics of system operation, thereby promising savings never before attainable with all-analog dispatching systems.

Digital-Analog Combination

An all-digital dispatching system is perfectly capable of handling all system functions, from solving the economic dispatch equations to direct control of system generation. There is much to be said for such an all-digital system. However, an all-digital system requires considerable computer capacity, and may thereby limit the future applications of some computers to less important system operation tasks. Since analog systems are very capable of balancing system generation with load demand by closed-loop regulation, the combination of a digital computer directing an analog control loop also offers advantages. Memory capacity of the digital computer can be much smaller than if the digital computer is also used to simulate closed-loop generation control; or, from another standpoint, a digital computer of sufficient size and speed to conveniently handle economic dispatch calculations is prevented from becoming memory limited so that it has capacity to handle additional tasks.

Furthermore, the combined digital-analog approach used in the ADDAPS system offers the obvious advantage of providing analog control backup during periods of digital computer maintenance. This control backup advantage was a major consideration in the selection of the ADDAPS system by Arizona Public Service.

A block diagram of the ADDAPS system is shown in Fig. 1. The system consists of three functional areas, one digital and two analog: (1) the Prodac 580 computer system; (2) analog control loop; and (3) local generating plant control. Each area can operate independently of the others. Thus, all turbine-generating units can be operated manually from local generating plant control; the analog control loop is superimposed over the generating plant to regulate generation automatically; and finally, the digital computer is superimposed over the analog control loop to obtain completely automatic economic dispatch of the ADDAPS system.

Digital Computer

The heart of the Automatic Digital Dispatch and Processing System is the Prodac 580 digital computer. The entire dispatch program is stored in a core memory to provide fast access and execution, and avoid problems associated with reading portions of the program from drum memory for execution. Consequently, only a small portion of the computer's total capability is needed to perform the economic dispatch function.

The computer is coupled to the rest of the ADDAPS system through *contact closure output*, *contact closure input*, and *analog input* units (Fig. 1). Analog inputs provide the digital computer with system operating information, such as actual generated total power, net interchange of power, tie power, and individual generator base-load settings. Contact closure inputs inform the computer of the operating status of console switches, telemetry channels, and digital display keyboard in the analog control system. A new economic dispatch computation is initiated whenever a predetermined increment of change in the *total sustained load* on the system occurs. Sustained load is the total required generation from which relatively high-frequency load swings have been removed. If the change in sustained load remains within a prescribed tolerance, the computer can proceed on other lower-priority programs. However, when a change in sustained load exceeds the prescribed tolerance, the priority interrupt immediately frees the computer to proceed with a new economic dispatch computation. This method of programming makes efficient use of computer time, since there are periods during the daily load cycle when the sustained system load remains at a relatively constant level.

The computer transmits the results of its economic dispatch calculation through the contact-closure output to *stepping motors* (Fig. 1), which convert the digital outputs to analog inputs for the generator control loops. In effect, a stepping motor adjusts the base load point for each generator on the system. Feedback of the resulting base-load setting to the digital computer closes the stepping-motor control loops.

Analog Control System

Since the digital computer only acts on predetermined incremental changes in total sustained load, unnecessary economic dispatch calculations and waste of valuable computer time for short-lived system conditions are avoided. Therefore, to enable the generating units to respond immediately to instantaneous swings in required generation without a new computation of economic dispatch, the sustained load as last dispatched by the computer is continuously subtracted from total required generation to produce an analog *ripple signal*. The ripple load thus determined is apportioned among system turbine-generator units on the basis of response and capability of each unit. This action is accomplished at *generator control modules* (Fig. 1), which simulate generating unit loadings. The ripple load is added to the base-load already assigned the unit, but limited within the maximum allowable maneuvering range for the unit (by the limit *comparator*, Fig. 1) to determine the *desired power output* for the unit. All unit desired power output signals are fed back to the summing and integrating unit, so that if some units reach their upper or lower limit, the remaining unit loadings will be adjusted accordingly.

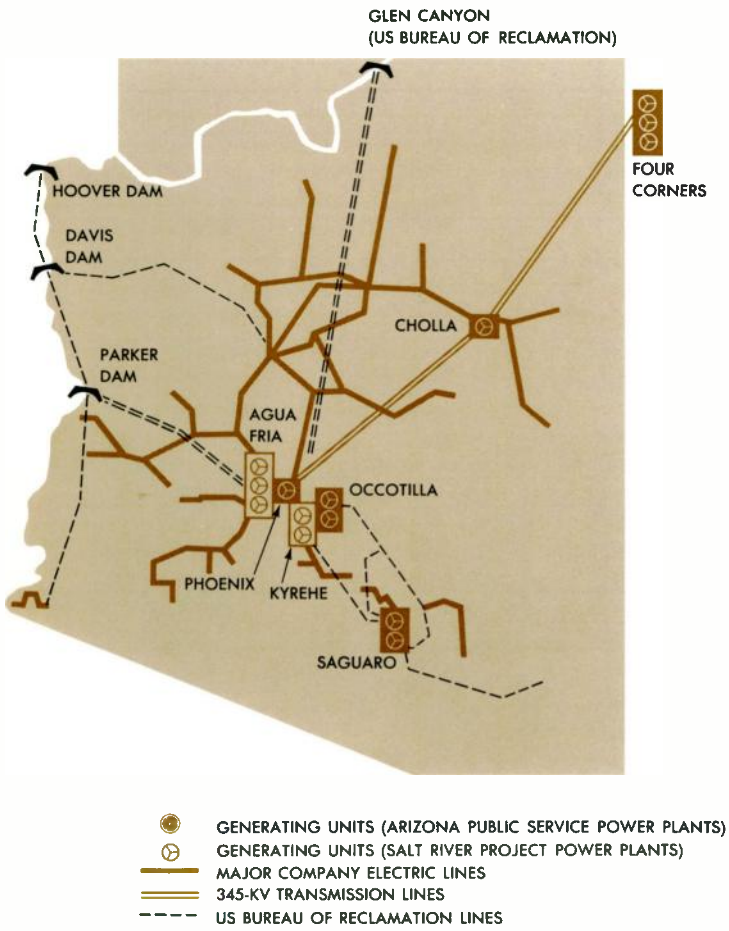
The function of the remaining portion of the analog control loops is to achieve a nonoscillatory balance between the actual power output and the desired power output of each generating unit. The *pulse-width computer* compares desired power with actual power, and produces *raise* or *lower* pulses for each unit. Rate-limiting and anticipation circuitry in the pulse-width computer insures that the contradictory requirements of altering unit load smoothly in a minimum time and yet not exceeding certain rates of change of generator output are satisfied. The dispatcher has the option of selecting a slow rate of one percent per minute, or a normal rate of three percent per minute. Turbine valve points are crossed smoothly with this system since one-percent control pulses are transmitted to the turbine-generator unit until machine response

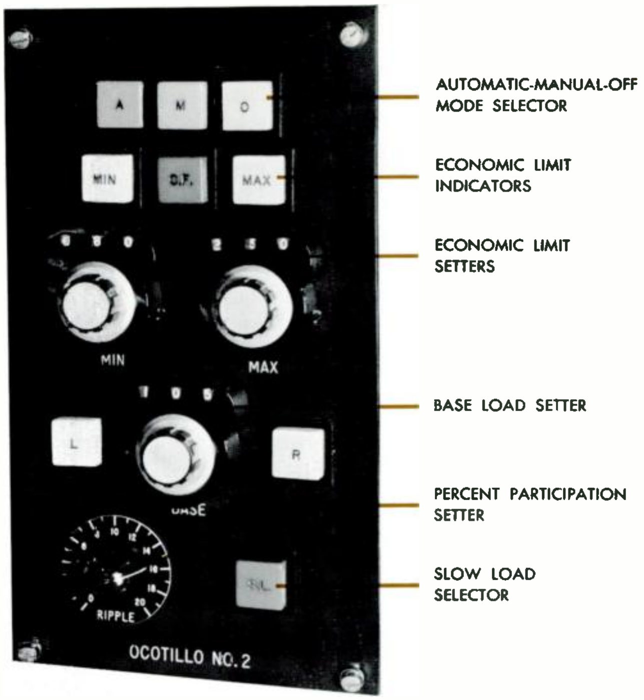
Major Transmission Lines in Arizona

The Phoenix Valley of the Sun area is served by two major utilities, the Arizona Public Service Company and the Salt River Project. The companies have franchised areas existing side by side. Presently, the total generation is approximately 1400 megawatts, with a projected estimate in 1980 of about 4500 megawatts. There are 7 different plants under control, with a total of 14 generating units. The unit locations range from 300 miles away in the Four Corners area to those in the valley proper.

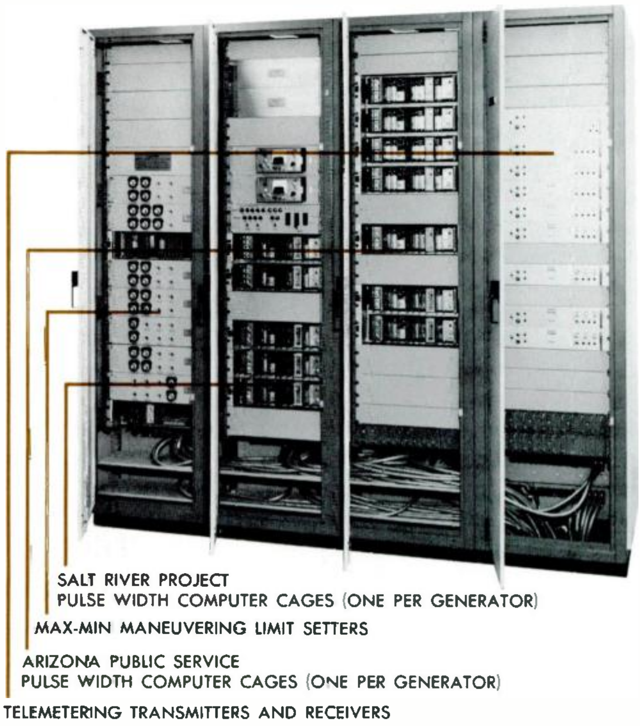
The simplified system map shows location of the APS and SRP generators and major transmission lines in the state of Arizona. Note that some segments of the APS system are interconnected by U. S. Bureau of Reclamation transmission lines. Some APS customers therefore receive power supplied by APS generators transmitted over USBR lines. This wheeled power increases the USBR line losses by an amount called wheeling loss. Wheeled power and wheeling loss are in addition to scheduled power interchanges between the APS-SRP pool and the USBR system. Calculation of wheeling loss and maintenance of interchange schedules by the ADDAPS computer relieves the dispatcher of an important time-consuming task.

For many years operating agreements have existed between the two companies, insuring a high degree of service reliability for the customers served by both utilities. The ties and method of operation have been such that, effectively, generation has been dispatched to the Valley of the Sun pool as though it was being served by one large utility. It was obvious to both companies that economies in generation could be achieved by joint automatic economic dispatch of the combined generation of both utilities. From this philosophy between the two companies grew the ADDAPS concept and the cooperative agreement to purchase and put into operation such a system.





GENERATOR CONTROL is accomplished from a module (one for each controlled generator) located in the dispatcher's console. This arrangement permits convenient communication between the dispatcher and the computer.



DISPATCH OFFICE ANALOG EQUIPMENT is contained in four equipment cabinets, from left to right: maneuvering limit setters, power supplies, generator controller cages, and telemetering equipment.

shows the valve point has been crossed and the turbine is responding normally.

Closing the Analog Loop with Telemetry

Each generating control loop has its own telemetry control channel for dispatching raise-lower signals to its associated generating plant.

The raise-lower pulses from the pulse-width computer key a frequency-shift tone channel up or down for a variable period of time, depending upon the amount of correction required. A base "at rest" frequency is continuously transmitted to provide channel failure sensing. In case of a microwave communications channel failure on either a control channel or a feedback channel, both channels are tripped and the computer automatically alerted of the failure. The generator is automatically returned to plant manual control and the output of further control pulses to the unit is interrupted until the channel difficulty is corrected. Also, if a failure is detected in the output control pulse (by the *long pulse* lockout), the generator is placed automatically under plant manual control until the difficulty is corrected.

The actual power generated signals are telemetered back to the *summing and integrating unit* by means of variable frequency quantities that modulate tones to complete the analog control loop.

Dispatcher Control

The dispatcher, from his control console, controls the same base-load setter potentiometers in the generator unit control loops that are controlled by the digital computer. This insures that the system will not receive a bump when control is transferred from *manual* to *automatic* operation. Thus, the only difference between the automatic and manual mode of operation is that when the system is under automatic control, the computer sets all of the base setters virtually simultaneously to the new base settings derived from the latest economic dispatch calculations and unit allocation information. The stepping motor that the computer pulses to move a setter to a new position is electrically disabled if the dispatcher switches that particular generating unit to manual operation.

The dispatcher can disconnect any generating unit from the ADDAPS control system and retain control over the remaining units. When a generating unit is removed from ADDAPS control, the *actual power* and *desired power* signals of that unit are also removed as inputs to the summing and integrating unit. Also, the output from the pulse-width computer is prevented from sending raise or lower pulses to the station.

Through the use of illuminated mode-selector switches, the dispatcher can quickly determine which units are *off*, how many are on *automatic*, and how many are under *manual* control during start-up or shutdown operations.

The dispatcher also can restrict the operation of each generating unit inside the pre-established economic limits for that unit. This economic limit range is within the maneuvering limit range of the unit established by machine limit setters in dispatch office analog equipment cabinet. If the chosen economic limit interferes with a desired base setting called for by the computer, an appropriate signal light alerts the dispatcher.

The priority system used in the Prodac 580 control computer allows the programmer to arrange all control programs according to priority. When a particular process interrupt occurs, a bid is placed for its associated program to run. If this program bid is higher than the current program, a priority executive program suspends the execution of the current program and begins executing the new high priority program. This program continues until interrupted by a higher bid placed in the priority bidding table, or until it removes its bid and returns control to the priority executive program.

Through an interpretive mode of program execution, an off-line program can be run from the programmer console without interfering with the control programs. Program location limits are set to prevent the execution of any instruction in the new program that could either alter or jump to a core memory location outside of the interpretive limits. Thus, the programmer's console is a powerful aid in debugging and assembling new programs. Through it, the programmer can safely communicate with the computer and not disturb any real-time commitments imposed by the power system controller.

A set of diagnostic programs periodically monitors the digital computer and its input-output equipment for any malfunctions. If a malfunction is detected, the dispatcher is notified by both warning light and bell alarm.

Emergency Power Supply

In the event of loss or surge of ac power at the pool dispatch office, the ADDAPS system will continue to operate for at least thirty minutes, to allow either restoration of power or correction of the distribution regulation problem. This is accomplished in the ADDAPS system by sensing line disturbances within a half cycle, and transferring the computer to a battery-powered inverter. The oscillator for the solid-state inverter is continually running and synchronized with the ac input line. A comparison circuit detects errors in wave shape of the incoming ac supply, and initiates the transfer. Filters prevent a single line spike from accidentally initiating transfer. A five-second delay before transferring back to line power after an outage insures that the number of false transfers during a series of power failures will be minimized. When the emergency power supply is energized, an alarm light and bell signal the dispatcher. Appropriate alarms are also provided to inform the dispatcher of any unusual conditions in the emergency power supply.

Economic Justification

The economic evaluation of the ADDAPS system predicts that savings due to system economic dispatch alone will recover system investment in about ten years. The application of additional optimization concepts to system operation made possible by the spare capacity and flexibility of the digital computer should produce additional operating economies. For example, some of the data processing capability of the computer is already being used for energy interchange billing. Further on-line applications are expected in the near future in such operations as energy accounting, optimization of generating capacity, outage diagnosis, and procedural steps for service restoration.

Protective Relaying for EHV Systems

*J. L. Blackburn, Relay-Instrument Division,
Westinghouse Electric Corporation, Newark, New Jersey.*

A variety of pilot relaying systems are available to suit the needs of EHV lines, including a new distance phase-comparison scheme that is particularly useful on lines with series capacitors. Back-up protection will be emphasized on EHV transmission lines.

Four basic relaying schemes for pilot protection are in use or scheduled for use on EHV lines. These schemes are outlined in Fig. 1. Each has many variations, including a scheme that combines directional comparison for phase faults with phase comparison for ground faults. The reasons for the variety of methods involve many subtleties, but a fundamental consideration involves the two basic but conflicting requirements of reliability—*dependability* and *security*. The question is whether it is more important to clear faults (dependability) or keep the system intact (security). Obviously, the primary objective is to provide both features, and both are provided by all of the pilot-relaying systems. Thus, the question involves relatively small hills and valleys of possible contingencies —all on the same high plateau of protection reliability. But this question accounts for much study and discussion among relay engineers.

The fundamental method of operation of the various pilot-relaying systems can be divided into two general categories—*blocking*[2] and *transfer trip*.[3] In a blocking system, the pilot channel provides a path for a signal that prevents tripping; in a transfer-trip system, the pilot channel provides the path for a tripping signal. Thus, a blocking system does not require a channel for simultaneous tripping during a fault, but any momentary delay or loss of blocking on any of the unfaulted lines in the area of a fault can result in an undesired trip—hence this system tends to be more dependable but less secure. With a transfer-trip system, a channel is required to assure simultaneous tripping, but undesired tripping from faults on adjacent lines is minimized because the fault must be within the reach of the fault detectors and an incorrect channel signal must be received from the remote terminal to produce tripping. Thus, the transfer-trip system tends to be more secure but slightly less dependable.

Relaying Communication

Channel requirements and availability are important considerations in choosing a relaying system. Channels that can be and have been used for pilot relaying are:

1) Power-line carrier—a 30- to 200-kc signal is superimposed directly on the transmission line.

2) Pilot wires—privately owned or leased from a telephone company—are used to compare low-level 60-cycle signal voltages, or to transmit audio tones (595 to 2975 cycles).

3) Microwave—around the 2500 and 6800 megacycle bands—is beamed between terminals.

Power-line carrier is the most commonly used channel for relaying major transmission circuits and is usually applied with blocking-type relaying systems. Modern transistorized sets are available with either a narrow-band one-watt output, or a somewhat wider-band 10-watt output, both with a channel operating range of 40 db.[1] The one-watt set provides narrow bands that can be closely spaced to allow more channels in already crowded spectrums; they have proven very adequate and reliable for 230-kv lines and below. The 10-watt set provides a greater signal-to-noise ratio margin for EHV lines with higher radio noise levels. Apple Grove tests indicate that this carrier design will perform satisfactorily and has ample signal-to-noise ratio.

Transfer-trip relaying with power line carrier requires sending the signal through the fault for simultaneous tripping. For close-in, three-phase faults at either end or faults at channel terminal connections, the carrier signal is essentially shorted so that its dependability is questionable, even with high-powered carrier sets. However, this scheme is being used by at least one large power system in this country[4,5] and it is used extensively outside the United States. Good operating experience has been reported, which might be expected since the probability

1 SUMMARY OF RELAYING SYSTEMS

Scheme	Operation	Relay Family Types
Directional-Comparison Blocking	Fault relays at each end of protected line sense fault power direction, and if power is flowing *into* the section from the several ends, tripping is *permitted*. For external faults, the power flow out of the protected line establishes a blocking signal to prevent tripping at all terminals.	Semistatic or static compensator distance relays SKA static logic and comparison
Phase-Comparison Blocking	The three-phase line currents at each end of protected line are converted to a single-phase voltage proportional to the input currents. The phase angles of these voltages are compared to determine if the protected line is faulted. If the currents are out of phase (or no signal is received from the remote end), tripping is *permitted*.	HCB* or SKB static phase comparison TCU static logic unit Semistatic or static compensator distance relays (optional)
Underreaching Transfer Trip	A *trip signal* is initiated by fault relays at either end of the line; each relay reaches more than 50 percent but less than 100 percent or must overlap the protected line. This tripping signal is transmitted to the remote breaker. The trip signal may either trip the remote breaker (*nonpermissive*), or permit the remote breaker to be tripped by its own local fault detector (*permissive*).	Semistatic or static compensator distance relays KDXG ground distance TT-17 channel auxiliary
Overreaching Transfer Trip	The *trip signal* is keyed by fault relays that reach through the entire protected line. To trip, both local keying relay and remote relay must operate.	Semistatic or static compensator distance relays TT-12 channel auxiliary

**This is a phase-comparison system where the 60-cycle voltages proportional to fault current levels are directly compared over a pilot pair. Hence it is not a blocking type in the accepted sense of the word.*

of either solid or three-phase faults at the ends of lines is relatively low.

Pilot-wire channels have been used with phase-comparison protective relays for over 25 years. In view of the vast number of terminals in operation throughout the world, this combination has a most enviable performance record. Security problems with leased channels have been minor, but nevertheless real.[6] This type of pilot-wire relaying is limited to short transmission circuits because of pilot-wire resistance and economics. In EHV, this scheme is being applied to cable sections and for protecting extended circuits between the unit-generator transformer and the line ring bus.

The application of transfer tripping schemes with audio tone channels is increasing. Recent advances in the design and application of audio tones, and the increased interest and awareness of the protection requirements by the telephone companies, has resulted in channels that are both dependable and secure.

Microwave channels also provide good reliability. Battery-operated sets have materially reduced the hazard of channel failures during power-system faults. Nevertheless, most microwave installations have been used for nonrelaying functions.

Carrier superimposed on the ground wire has been considered as a possible relaying channel medium. Although this technique has been used many years for voice communications with satisfactory results, its dependability during faults or trouble periods is doubtful. Many faults will cause the ground wire gaps to flash and the fault current return in the ground wire provides power follow to maintain the arc, thus highly attenuating or shorting the carrier signal. Increasing the ground wire insulation would negate the primary function of the ground wire and make it uneconomical. This area requires further field testing and study before final conclusions can be reached.

Comparison of Relaying Systems

As previously indicated, comparisons of the various pilot relaying systems cannot be exact. Each form has its advantages and limitations, and all have been highly successful in service. Any attempt to rate the various systems must therefore be arbitrary. Dependability and security have already been discussed from the standpoint of blocking versus transfer-trip operation. Other parameters will also affect reliability.

Underreaching versus Overreaching—Underreaching systems are quite simple, and this simplicity accounts for their high dependability. The application criterion is that the operating zones of both the phase and ground protective relays at the line terminals must overlap but not overreach the remote terminals under all system-operating conditions to assure simultaneous tripping. On long two-terminal lines, phase-distance and ground-overcurrent relays usually can be applied to meet these requirements. For shorter lines, ground-distance relays are applicable, but these relays tend to negate the advantage of simplicity.

The overreaching transfer-trip scheme is suitable for both long and short lines, two-terminal or multiterminal. They are preferred over the blocking systems for microwave or pilot-wire audio tone applications because of their high security and because phase and ground carrier start units are not required. There is no question concerning dependability as there is with transfer-trip carrier systems for faults near the coupling locations.

More sensitive settings are possible with the over-

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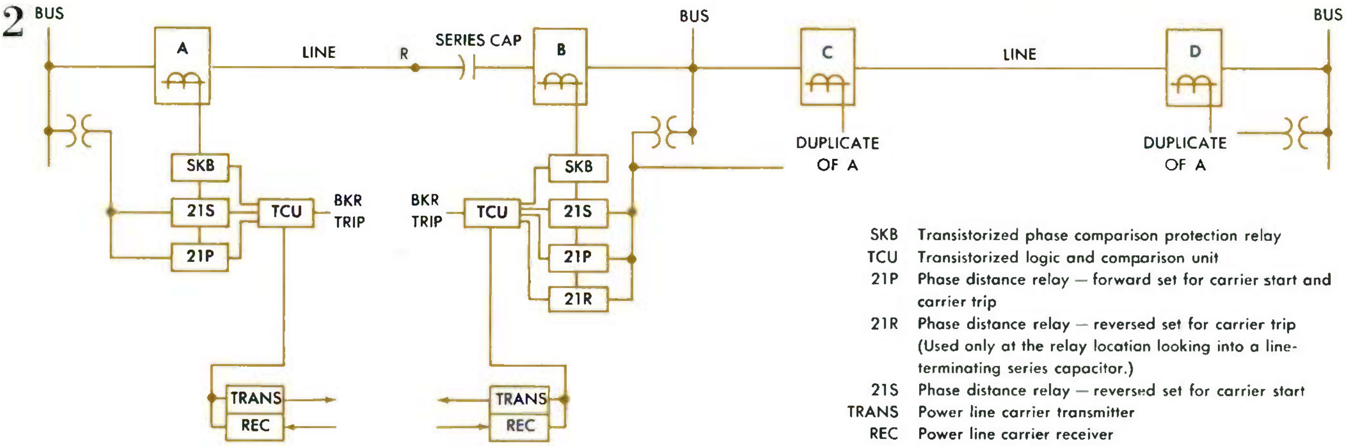


SKB	Transistorized phase comparison protection relay
TCU	Transistorized logic and comparison unit
21P	Phase distance relay — forward set for carrier start and carrier trip
21R	Phase distance relay — reversed set for carrier trip (Used only at the relay location looking into a line-terminating series capacitor.)
21S	Phase distance relay — reversed set for carrier start
TRANS	Power line carrier transmitter
REC	Power line carrier receiver

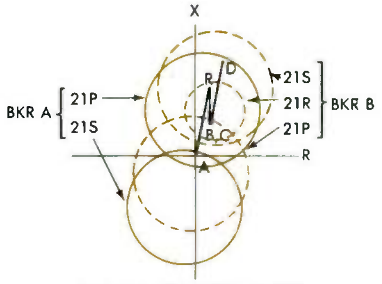
Distance Phase-Comparison System

The SKB-TCU phase-comparison system[1] alternately compares the relative phase of the fault currents at the local and remote terminals of the protected line. The TCU logic circuitry is provided with local and remote half-cycle square wave pulses of carrier: for an internal fault, these pulses are in phase so that tripping output is permitted during half-cycle intervals when carrier blocking pulses are not present; for external faults, local and remote carrier pulses are out of phase, and therefore provide a continuous blocking signal to prevent tripping.

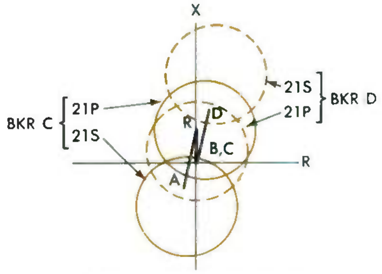
In a conventional phase-comparison system, overcurrent relays supervise the operation of the blocking and tripping functions. A low-set detector initiates carrier transmission of blocking pulses, and a high-set detector supervises the local tripping signal; both detectors must pick up for tripping to occur. In the new distance phase-comparison scheme, these overcurrent fault detectors are paralleled with compensator distance relays (*21P*, *21S*, and *21R*). Relays *21S* replace the low-set fault detectors at both terminals, and *21P* (and *21R* when required) replace the high-set detectors. Both *21S* and *21P* must start carrier in the distance phase-comparison system because the blocking pulses for all external faults are alternately shifted each half cycle between the local and remote terminals.

Typical settings for the three-phase compensator distance relays are shown in the R-X diagrams. For line *AB* (top right), relay *21S* at *A* must reach farther behind *A* than does *21P* at *B* to assure correct blocking for external faults. Correspondingly, *21S* at *B* must reach farther behind *B* than *21P* at *A*. At breaker *B*, an additional trip fault detector (*21R*) is required because the *21P* three-phase unit at this location cannot see internal faults in the area *R*. Settings with the same criteria are shown for the line *CD* in the lower R-X diagram.

The phase-to-phase unit of the compensator relays is not shown on the R-X diagrams. The phase-to-phase unit has a circular characteristic that varies with source impedance with the reach along the protected line or the compensator phase angle remaining constant.[2] This unit does not respond to load, and therefore provides far better protection than any other distance-type characteristic, particularly for the series capacitor.



LINE A-B DISTANCE RELAYS
TYPICAL SETTINGS



LINE C-D DISTANCE RELAYS
TYPICAL SETTINGS

reaching system so that the relays operate at a higher multiple of their pick-up values for all internal faults. Thus, the overreaching systems tend to be faster than the underreaching types.

Permissive or Nonpermissive—Both the comparison blocking and overreaching systems are permissive; that is, local fault detectors supervise or permit tripping called for by the remote relays via the pilot channel. More dependable but less secure are the nonpermissive transfer-trip and pilot-wire (HCB) phase-comparison types; however, these relaying schemes are seldom applied without adding permissive fault detectors at the local terminals to supervise and permit tripping. The phase-comparison blocking system (SKB) is a permissive type system, utilizing either current or distance fault detectors.

Directional- vs. Phase-Comparison Blocking—The prime advantage of the directional-comparison system is its extreme flexibility to all types of applications, multiterminal lines, and system changes. On the other hand, the phase-comparison system, which uses current only, has no difficulties with power swings, series capacitors, induced zero-sequence current, or inadvertent loss of potential. Its main difficulty is its insensitivity to three-phase faults, and the inability to distinguish between light three-phase faults and heavy loads. Thus, its application has been restricted to short two-terminal lines. A combined phase- and directional-comparison scheme uses directional-distance relays for phase faults to circumvent the three-phase fault sensitivity problem, but retains the advantage of immunity to incorrect directional sensing to induced zero-sequence current. (The directional-comparison system with negative-sequence polarized directional ground relays also provides immunity to induced zero-sequence current). The other advantages of the phase-comparison system (immunity to swings, series capacitor, inadvertent loss of potential) are lost in the combined scheme.

Series Capacitors

Because many of the EHV lines now under consideration are long, they present stability problems. As EHV systems expand with more interconnections and paralleled circuits, stability problems will be reduced; but for the next several years the series capacitor is being considered to reduce system reactance and increase power-transfer capability. The capacitor presents difficult relaying problems to which a general overall solution is not applicable. Each installation must be specifically studied and a particular solution worked out. Thus, EHV system planning and protection must be closely coordinated.

The capacitive reactance drop introduced by the series capacitor in a basically inductive electrical system changes current and voltage relationships during faults and hence affects the fault or trouble indicators that are sensed by protective relays.

A typical series capacitor system is shown in Fig. 2. At *A* the fault current decreases as the fault location is moved from *A* to *R* but increases as the fault is moved from *R* to *B* and *C*, and again decreases as the fault is moved towards *D*. The voltage drop across the capacitor is opposite to the line voltage drop. The net result is that phase overcurrent, directional and distance relays at the terminals in the area of the capacitor all have difficulties in "seeing" faults in their conventional protection zones as well as not "seeing" faults outside these zones.

The series capacitor will have protective gaps across the unit that short out the capacitor when current exceeds about 250 percent of rated. In most of the series capacitors installed to date, and in many applications planned for the future, these gaps will effectively short out the capacitor unit for all faults that cause trouble for directional- and distance-type relays. In these cases, the directional-comparison and transfer-trip relay systems with distance and directional over-current back-up relays can be applied, but relay operating times must not be less than about one-half cycle.

When capacitor gaps will not flash for faults for which the relays should operate or discriminate, then a phase-comparison pilot relaying system must be used. Phase-distance relays are used in these applications as fault detectors to give increased discrimination between three-phase faults and load.

The phase-comparison system will operate correctly with or without the series capacitor in the circuit as long as the net impedance from the fault to the source is inductive. If the net impedance to a source becomes capacitive, a 180-degree current reversal occurs with respect to the generated voltage. The current phase relations at the line terminals make an internal fault appear to be an external fault to the relays, and relays go berserk. Experience indicates that a 180-degree current reversal is likely for a large series capacitor, but that for the faults where a reversal occurs the current magnitude is large and should cause gap breakdown.

Distance Phase-Comparison

A modified phase-comparison system utilizing phase distance relays as fault detectors has been developed and applied for protecting lines involving series capacitors. It is equally applicable to lines without series capacitors. This scheme is shown functionally in Fig. 2. It retains most of the key advantages of the phase-comparison scheme—immunity to power swings so that out-of-step blocking is not required, and immunity to incorrect operation on parallel line zero-sequence induction. The distance fault detectors improve the security and increase the three-phase fault sensitivity.

By offsetting the distance characteristic so that it surrounds the origin as shown in Fig. 2, instantaneous tripping will occur when using line-side potential and when closing into a bolted three-phase fault at the relay location. Directional discrimination is not lost by this offset since this discrimination is supplied by the phase-comparison system.

This combination is new and promises to be the best all-around scheme for EHV and other important transmission circuits where power-line carrier provides the relaying channel.

Other advantages of the distance phase-comparison scheme are its applicability to three-terminal lines. The scheme does require potential for the distance relays but it can be made immune to undesired tripping upon loss of potential by continuous keying of the carrier channel.

Shunt Capacitance

Line-charging kva is proportional to voltage, line length, and conductor size and number, and therefore is much higher for EHV lines. Most of these lines have bundled conductors so that series impedance is decreased. The surge impedance of the bundled-conductor line is about 300 ohms compared to approximately 400 ohms for a single-conductor line. The classical typical values of 0.8 ohm per mile series reactance and 0.2 megohm per mile shunt reactance change to 0.6 ohm per mile and 0.14 megohm per mile respectively for 500-kv, bundled-conductor lines. An analog computer study of the transient nature of the charging current on a typical 500-kv line has indicated that there will be little initial transient disturbance upon energization. Charging current has not been a problem in any of the present relaying systems and this situation does not appear to be significantly changed by the higher voltages unless relaying times are reduced to well under one-half cycle.

Single-Pole Tripping and Reclosing

For single-line-to-ground faults on the transmission line, which are usually the predominant type, opening the faulted phase pole and reclosing it to restore three-phase service for transient faults has been suggested and considered on EHV lines. The advantages are reduction in switching surges on the unfaulted phases and increased stability. It is economically more feasible with the individual mechanisms on each pole in the live-tank breaker designs for EHV than for the single-mechanism dead-tank breakers, and it is in wide use in Europe. The problems and disadvantages are: (1) a probable long reclosing time (approximately 1 or 2 seconds at 500 kv) required to insure extinction of the fault arc; (2) a somewhat more complex relaying system; and (3) the necessity to reset or delay the operation of ground relays over the system to avoid tripping while the one phase is open. K-Dar relaying

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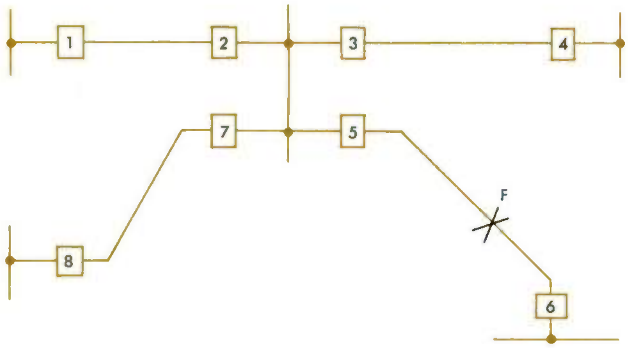

Back-up Protection failure of relay or breaker or both at *5* to clear fault *F* can be obtained by *remote, limited-remote*, or *local back-up:*

Remote Back-up—Relays at *1*, *4*, and *8* must see the fault and open their respective breakers.

Limited Remote Back-up—Because of the high fault-current infeed from other lines, it may be difficult for the remote relay to "see" faults at the far end of adjacent lines; for example considering relays at *8*, when fault *F* is near breaker *6*, relay *8* may have extreme difficulty or find it impossible to "see" this fault because of the large fault current flowing to the fault from lines *1-2* and *3-4*. Thus, the back-up offered by the relay at *8* for line *5-6* may be limited to the part of the line near breaker *5*. This is why remote back-up protection is becoming more untenable on systems with many interconnections.

Local Back-up—Either primary or back-up relays for line *5-6* initiate a time delay *supervised* by fault-current magnitude to clear fault by opening breakers *2*, *3*, and *7*.

4 COMPARISON OF REMOTE AND LOCAL BACK-UP PROTECTION

Remote Back-up

Advantages	*Disadvantages*
1. Relatively inexpensive	1. Usually slower speed
2. Backs up all elements of protection system, including battery	2. Less sensitive. Relays often difficult or impossible to set for complete back-up, and frequent compromises are required
3. Minimum complexity equipment	3. Entire station is unnecessarily interrupted
	4. May cause unnecessary interruption of service on multiterminal lines

Local Back-up

Advantages	*Disadvantages*
1. Faster Operation	1. Duplication of relays, CT etc. required for maximum protection
2. More sensitive protection	2. More complex and hence increased potential for incorrect operations which can dump a major bus
3. Easier to set relays	3. More expensive
4. Generally provides more complete back-up, particularly on multiterminal lines	

systems are available for single-pole tripping and reclosing; such installations are in service at 230 and 345 kv in foreign countries.

Back-up Relaying Systems

The requirements for protection against more contingencies at EHV has put more emphasis on *back-up protection*. The application of high-speed primary protection supplemented by a reasonably independent, fast, back-up protective system is recommended and is being used not only for EHV but for other important transmission lines.

The classical method of providing back-up protection for lines has been to apply a common set of protective relays for both the primary and back-up functions. The relays are set to provide primary protection for the immediate line section and back-up protection for the next line section. To minimize the application problems and provide maximum primary protection, directional type relays are used. Thus, they operate only if the fault is on the immediate line section or on the system off the remote bus. This form of back-up—back-up for the adjacent system—is known as *remote back-up*, and is demonstrated in Fig. 3.

A major difficulty with remote back-up is the difficulty and often impossibility of providing coverage for all of the adjacent line or lines off the remote bus. Other circuits feeding into this bus will appreciably reduce the back-up coverage. Thus, remote back-up may be limited for adjacent lines under some conditions. This situation is aggravated on multiterminal lines.

Since satisfactory remote back-up protection is becoming increasingly difficult in highly interconnected power systems, the trend is to local back-up, as shown in Fig. 3. The major advantages and disadvantages of remote and local back-up are summarized in Fig. 4.

In designing a back-up protection system, the protective function and the objectives should be clearly defined. A typical example is shown in Fig. 5. In this case, primary and back-up protection for line *1-2* can be provided by combinations of the pilot protection systems, or by a pilot protection system for primary and distance type relays for back-up.

Many combinations can be put together. An example of two pilot systems would be one with power-line carrier and another with microwave. Another would be the use of two sets of HCB pilot-wire relays for the protection of an important circuit. These are connected to separate current transformers and operate over pilot wires with different routing. In this case both operate instantaneously so that in reality there are two sets of primary relays.

The compensator distance relays[7] are particularly applicable in local back-up schemes because each zone is packaged separately. The zones can be connected to separate current and potential transformers with their control and trip circuits separated completely even to operating separate trip coils if available. Excellent primary and local back-up protection can be obtained with either a three- or four-zone system.

While distance-type relays are in wide use for phase faults, conventional directional instantaneous and time overcurrent relays have been used for ground fault back-up protection. The difficulty of coordinating overcurrent

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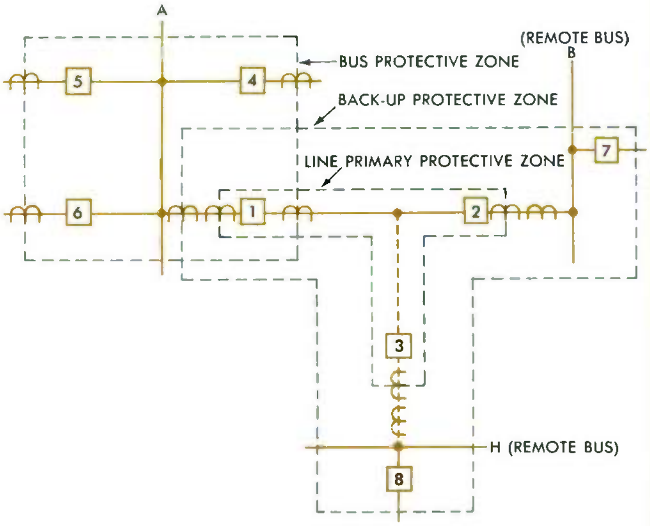

Functional Objectives for protecting the bus *A* and line *1-2* between *A* and *B* are:

Relay Protection Function	*Objectives*
1. Bus	1. Rapid isolation for all faults in the bus protective zone by opening breakers *1*, *4*, *5*, and *6*.
2. Line Primary	2. Rapid isolation for all faults in the line primary protective zone by opening breaker *1*.
3. Local back-up	3. Back-up short time isolation for all faults (a) in primary protective zone (b) on remote bus, and (c) in a limited zone on the lines or equipment connected to the remote bus.
A. For breaker failure	A. Open breakers *4*, *5*, and *6* if breaker 1 fails to clear the fault. Operation can be initiated by either the primary protective relays or the back-up protective relays.
B. All trouble except breaker failure	B. Open breaker *1* if the primary relays and associated circuitry fail to initiate tripping.
4. Optional Limited Remote Back-up	4. Back-up longer time isolation by opening breaker *1* for (a) failures of the primary and local back-up relays for faults in these zones and (b) faults farther out on the lines out of the remote bus.

The basic scheme and principles described above for line *1-2* breaker *1* should be applied at all other line breakers such as *4*, *5*, *6*, *7*, etc. Where this is not carried out, then the remote back-up described above under part *4* is required to assure back-up overlap.

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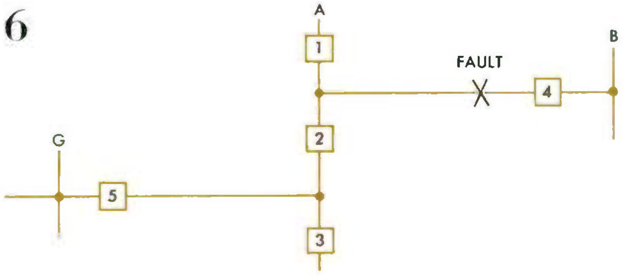


Breaker saving bus arrangements may require both local and limited remote back-up protection.

relays along with the longer operating times frequently involved on the shorter lines indicate that more consideration should be given to applying ground-distance relays for back-up. While the first cost is higher, higher speed back-up over more of the line section can be obtained. Equally important is the significant reduction in setting maintenance required in all protective systems as the power system expands and changes.

Both local and limited remote back-up protection will be required at buses where the number of breakers are reduced for economy, such as ring buses, breaker and a half, etc. A typical case is shown in Fig. 6. Breakers *5* and *3* must be opened if breaker *2* fails for all faults on line *AB*. Breaker *3* can be tripped by local back-up but breaker *5* requires remote back-up. As pointed out in Fig. 3, it may be difficult or impossible to set relays at *5* to cover bus *B* because of the fault infeed through breakers *1* and *3*. A practical solution to this situation is *sequential back-up*, where the redistribution of current and voltage caused by the opening of breakers *1* and *3* permits the relays at *5* to operate.

Summary

Relay principles and systems proven on lower voltage lines form a solid foundation for EHV protection. Such important circuits with their high economic investments require protection with a firm background of experience and reliability. Coverage for more contingencies than previously justified should be applied, which means not only careful emphasis on the primary protection but increased emphasis on back-up relaying and separation of the primary and back-up protective schemes.

A wide variety of line-relaying systems are available to suit the power system needs and individual preferences. These are generally suitable for use with any communication medium to achieve high-speed simultaneous clearing of all line breakers on the faulted line. They are compatible with the local back-up techniques which should be utilized on the EHV system.

The distance phase-comparison system combines the important advantages of the directional and phase-comparison schemes. This new scheme promises to be the best all-around scheme for major transmission lines utilizing power-line carrier, particularly where a series capacitor may be used.

When audio tones over pilot wires or microwave are used, the permissive overreaching transfer-trip system is preferred.

REFERENCES.
[1] "Transistorized Power-Line Carrier for Protective Relaying," H.W. Lensner, *Westinghouse ENGINEER*, September 1963, pp. 142-5.
[2] *Applied Protective Relaying*, B7235, Westinghouse Electric Corporation, P. O. Box 2278, Pittsburgh 30, Pa.
[3] "K-Dar Relaying Masterminds Fault Clearance," J. L. Blackburn, G. D. Rockefeller, *Electric Light and Power*, June 15, 1961.
[4] "Evaluation of Transfer-Trip Relaying Using Power Line Carrier," Working Group of the Line Relay Protection Subcommittee, AIEE Relays Committee, *AIEE Transactions*, 62-28.
[5] "Carrier Current Transfer-Trip Relaying Field Tests and Operation Experience," D. G. Wohlgemuth, D. A. Gillies, R. E. Dietrich, *AIEE Transactions*, 62-119.
[6] "Application and Protection of Pilot Wire Circuits For Protective Relaying," Pilot Wire Subcommittee, AIEE Relays Committee, *AIEE Special Publication*, S-117.
[7] "K-Dar Compensator Relaying," H. W. Lensner, *Westinghouse ENGINEER*, July 1959, p. 114-8.

Complex Diagrams Produced With Keyboard Machines

Major electronic systems, such as radar equipment, require hundreds of circuit drawings for manufacturing, installation, instruction, and maintenance purposes. Much of the time and effort required to produce this mass of drawings is eliminated by a new drafting process that produces high-quality drawings in about a fourth of the time (exclusive of changes) required to make inked drawings by conventional drafting. The new process also reduces drafting cost in an organization that produces at least two or three large drawings a day.

The Photo-Composed Drafting System employs photographic "typesetting" machines to compose drawings on photographic film. The system was developed for electronic diagrams, printed-circuit negatives, and electrical system drawings, but it can be modified to produce hydraulic and pneumatic diagrams or even to set music.

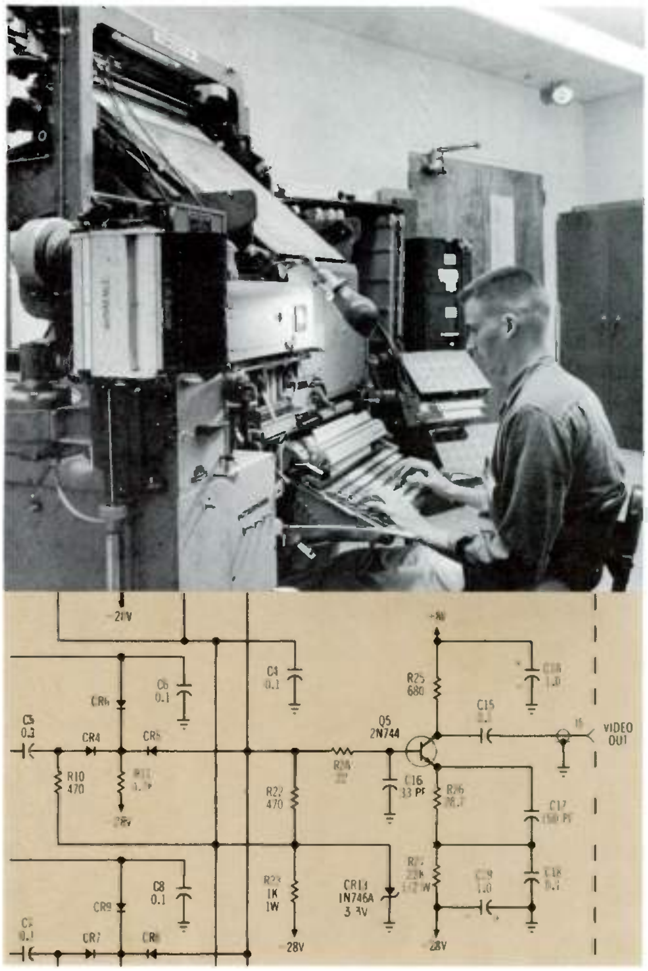
The system is based on the principle that a drawing is a body of intelligence expressed with a fixed vocabulary of characters (lines, symbols, and letters). Since the characters are used repetitively, they need be drawn only once and stored for repetitive use. (They are "drawn," in this system, as negative images in small pieces of metal called matrices.

The drafting process is begun by sketching the circuit on a special gridded sketch form and lettering the necessary nomenclature. The sketch form is divided into segments called folds, and each fold into horizontal and vertical lines of characters. Symbols and lines are located on this form in accordance with simple layout rules. The sketch form and special symbol templates lay out the drawing automatically, without any special effort.

A circuit operator then "sets" the lines and symbols (but not the nomenclature) on photographic film with a standard photographic typesetting machine. He works on one fold at a time, setting each horizontal line of characters from left to right and in sequence. The machine he uses is a keyboard device with the required matrices stored in two magazines. Pressing a key on the keyboard selects and releases a matrix from one of the two magazines. The machine assembles the matrices into a complete line of characters. The line is moved to a camera in the machine, where the images are projected on film. The machine then returns the matrices to their respective places in the magazines and proceeds with the next horizontal line.

In a simultaneous operation, the nomenclature for the drawing is set on a separate galley film with another keyboard machine.

The sketch, circuit film, and nomenclature film then go to a darkroom. A positive image is developed on the circuit film, and a negative image is produced on the nomenclature film. After proofreading and correction, the separate folds of the circuit film are assembled, and this assembly is contact printed onto a single sheet of autopositive film. The new circuit film is developed with a positive image, stopped, dried, but not fixed. The next operator works at a special light table that has both a safe light for viewing and a white light for printing. He prints the nomenclature on the circuit film.



STANDARD PHOTOGRAPHIC "TYPESETTING" MACHINES equipped with special characters assemble the lines, symbols, and nomenclature that make up a circuit drawing. Part of an electronic diagram made by the Photo-Composed Drafting System is reproduced above.

The circuit film is then developed again to bring out the nomenclature images. A print of this film (see illustration) is checked by the originating engineer. If it is correct, another film that includes border, alteration column, title box, and other standard details is made from it. This is the film from which working prints are made.

The system was developed by the Surface Division of the Westinghouse Defense and Space Center and by the Intertype Division of Harris-Intertype Corporation. Both companies have made the process available to other defense and space contractors.

Sonar Shows Ocean Bottom

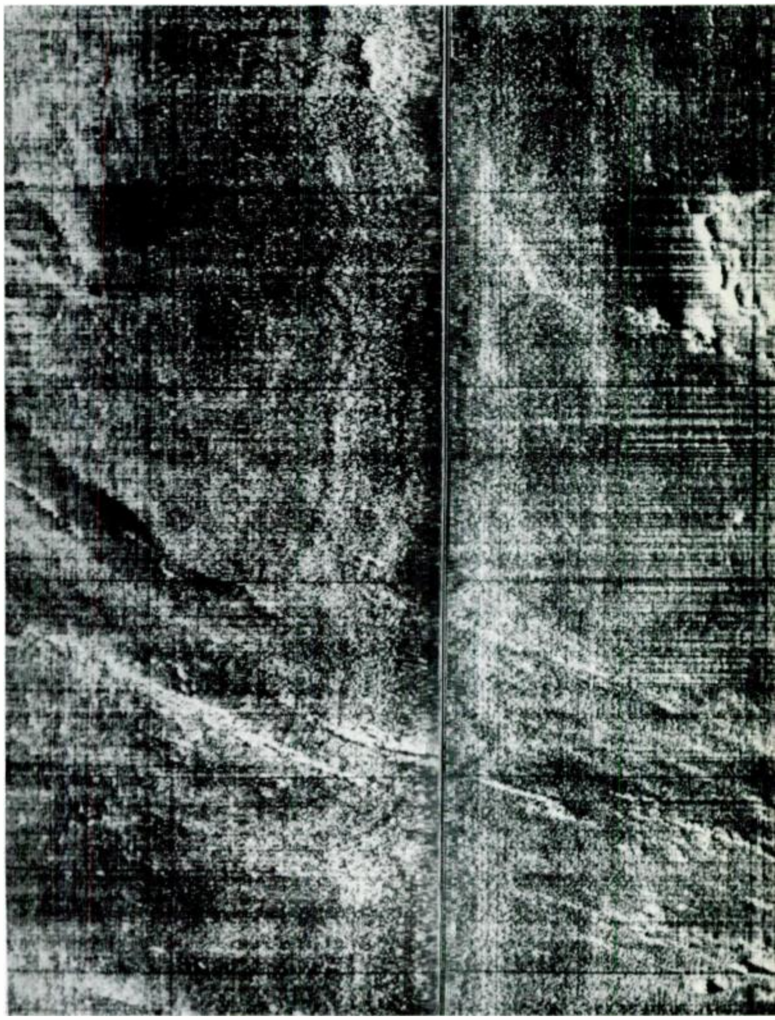
The ocean floor is being "photographed," at depths far too great for sunlight to penetrate, by new sonar systems. A sonar vehicle towed under water behind a surface vessel continuously scans the ocean floor with beams of high-frequency sound waves. The reflected energy is picked up and used to produce sharp clear pictures on a television screen or on a strip of sensitive paper moving through a facsimile recorder.

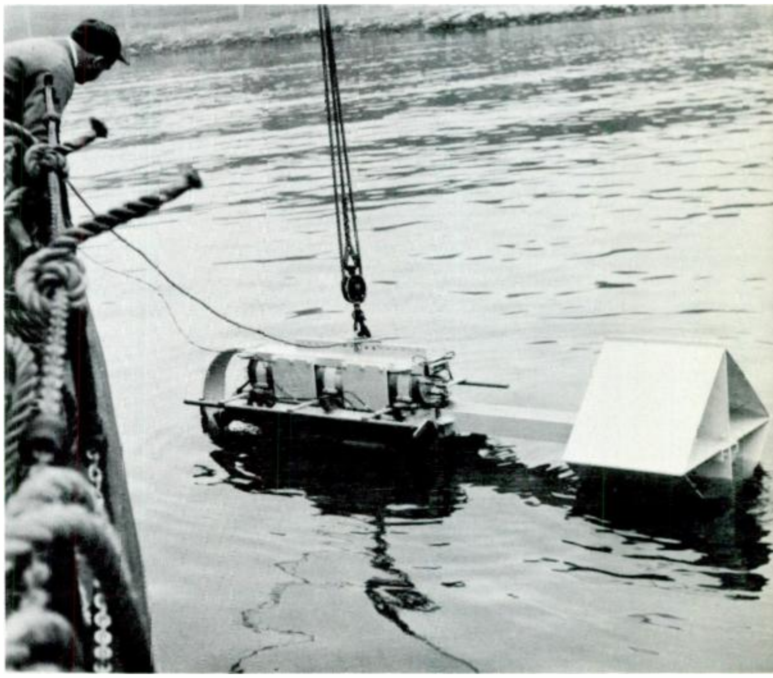
The systems are a step beyond conventional sonar, which can detect objects but has not had the combination of high resolution (picture detail) and long range needed to actually form a picture of the bottom. They can be designed with resolution and range to fit many needs, so they will be useful to geologists, oceanographers, and others interested in ocean-bottom topography.

A long-range version, designed for use down to 20 000 feet below the surface, was used by the U. S. Navy in the search for the sunken submarine *Thresher*. It has a search rate of 1½ square miles an hour. The system was developed by Westinghouse for the Office of Naval Research under contract to Hudson Laboratories, Columbia University.

The sonar vehicle for this system is 12 feet long, weighs 1500 pounds, and is towed from 200 to 400 feet above the ocean bottom at speeds up to four knots. Two sonar transducers—a transmitter and a receiver—are located on each side of the vehicle. The transmitter transducers convert high-frequency electrical pulses into ultrasonic vibrations. These travel outward through the water in a fan-shaped beam on each side of the vehicle, scanning the bottom from directly below the vehicle out to 1200 feet on both sides. The scanning is perpendicular to the direction of vehicle tow. The vibrations are reflected from the ocean bottom and converted by the receiver transducers to electrical signals. These signals are amplified by transistor circuitry and transmitted to the ship.

The display equipment builds up a picture from a series of parallel lines similar to the way in which a television picture is produced. Each line shows a strip along the bottom 2400 feet long and 4 feet wide. The strip is divided into 2½-foot elements in the 2400-foot, or sideways, direction. The system thus has a resolving capability down to 2½ by 4 feet. The resulting picture shows the hills, plains, and valleys of the ocean floor in considerable detail. Shadows cast by protruding objects give a three-dimensional effect.





FLOOR OF THE ATLANTIC OCEAN, 8400 feet down, was "photographed" by a sonar scanning system (top). The picture shows an area roughly one mile from bottom to top, the direction in which the sonar vehicle was towed, and half a mile wide. It was made by a facsimile recorder, which compressed the picture somewhat in the travel direction. The sonar vehicle for the scanning system (bottom) can operate as deep as 20 000 feet below the ocean surface. Its tail assembly stabilizes the vehicle as it is towed behind a surface ship.

Reclamation of Refuse

H. G. Furlow, *Assistant to the President, SACS, Inc., Shawnee, Oklahoma.*
H. A. Zollinger, *Materials-Handling Systems, Industrial Systems Divisions, Westinghouse Electric Corporation, Pittsburgh, Pennsylvania.*

A proven reclamation system salvages valuable scrap from household, business, and industrial refuse and converts the rest into a salable compost.

The modern urban complex as we know it could not exist without continuous disposal of refuse. This refuse—garbage, paper boxes, food containers, newspapers, yard clippings, and the many other things that we throw away—is produced from every residence and business in the community. Disposal of refuse has become one of the most difficult, expensive, and yet vital problems facing community officials today.

The idea of refuse *reclamation* by salvaging all material that has scrap value and composting the rest has become more and more attractive. (Composting is the controlled breakdown of plant and animal matter by microorganisms until it is stabilized in the form of a harmless granular material called compost, which is useful as a soil conditioner and mulch.) Some salvaging of scrap has long been practiced, of course, but modern processing and materials-handling methods now make an integrated approach feasible. (See *Development of Refuse Reclamation*, page 82.)

The Problem

A number of factors have interacted to aggravate the problem of refuse disposal. First, rising sanitation standards are making the traditional dumping and burning unacceptable. Two improvements have evolved—controlled dumping and burying with soil (sanitary landfill), and controlled burning of combustible constituents in special incinerators. However, climate, topography, or other factors make both methods unsuitable for many communities.

Sanitary landfill sites soon become filled and new sites require ever-increasing hauling costs; the practice sometimes pollutes streams and underground water; and careful planning and control are necessary to prevent nuisances. Incineration is relatively expensive, contributes to air pollution, and still leaves considerable residue that must be disposed of in a sanitary manner. These methods were developed more than 25 years ago, and few changes have been made since; probably no other "industry" of this size and importance has applied so little technology.

Another factor is the increasing urbanization of the population, which has made land for disposal expensive or unavailable. When it is available, its distance from the population center makes hauling costs prohibitive for many communities. The population also is increasing rapidly. Moreover, each of us produces more and more refuse. Studies 20 years ago showed an average refuse generation of two pounds per person per day; recent studies show some communities average more than five pounds per person, with the national average nearing four pounds. The increase probably reflects increased prosperity and use of more prepackaged products.

These factors have increased the costs of disposal by present methods until they are now exceeded only by expenditures for roads and schools in most communities.

The Process

A new reclamation process, developed by Naturizer, Inc., SACS, Inc., and Westinghouse, is a complete system for urban refuse disposal, one that is flexible enough to adapt to the varying needs of different communities. The process can handle most types of industrial, commercial, and residential refuse, except for such things as building rubble, automobile bodies, and large quantities of concentrates such as acids and poisons. Rubbish can thus be collected with garbage, saving the expense of double pickup.

The reclamation plants can be attractively housed and require only a small amount of land, which can be used permanently for the disposal site. They can be located close to the source of refuse, reducing hauling costs; they are completely pollution-free; and they reduce disposal costs through recovery of valuable products.

The process is made up of the functions of receiving, salvage, preparation, digestion, and finishing (Fig. 1). For example purposes, these functions are discussed for a generalized plant processing 300 tons of incoming material a day. The same overall approach is taken for larger or smaller plants, in any part of the country.

Receiving—Scales weigh trucks in and out for computing charges to the city or private collector. The refuse is dumped on the floor of the enclosed receiving area or directly into the receiving pit. Dumping on the floor provides an easy method of mixing loads of different types of refuse and facilitates removal of such large items as bed springs. Front-end loaders push the material from the floor into the receiving pit. Wood products such as tree limbs, yard trimmings, and reasonable amounts of lumber are sent through a shredder before they go into the receiving pit. This facilitates handling and speeds decomposition of the wood.

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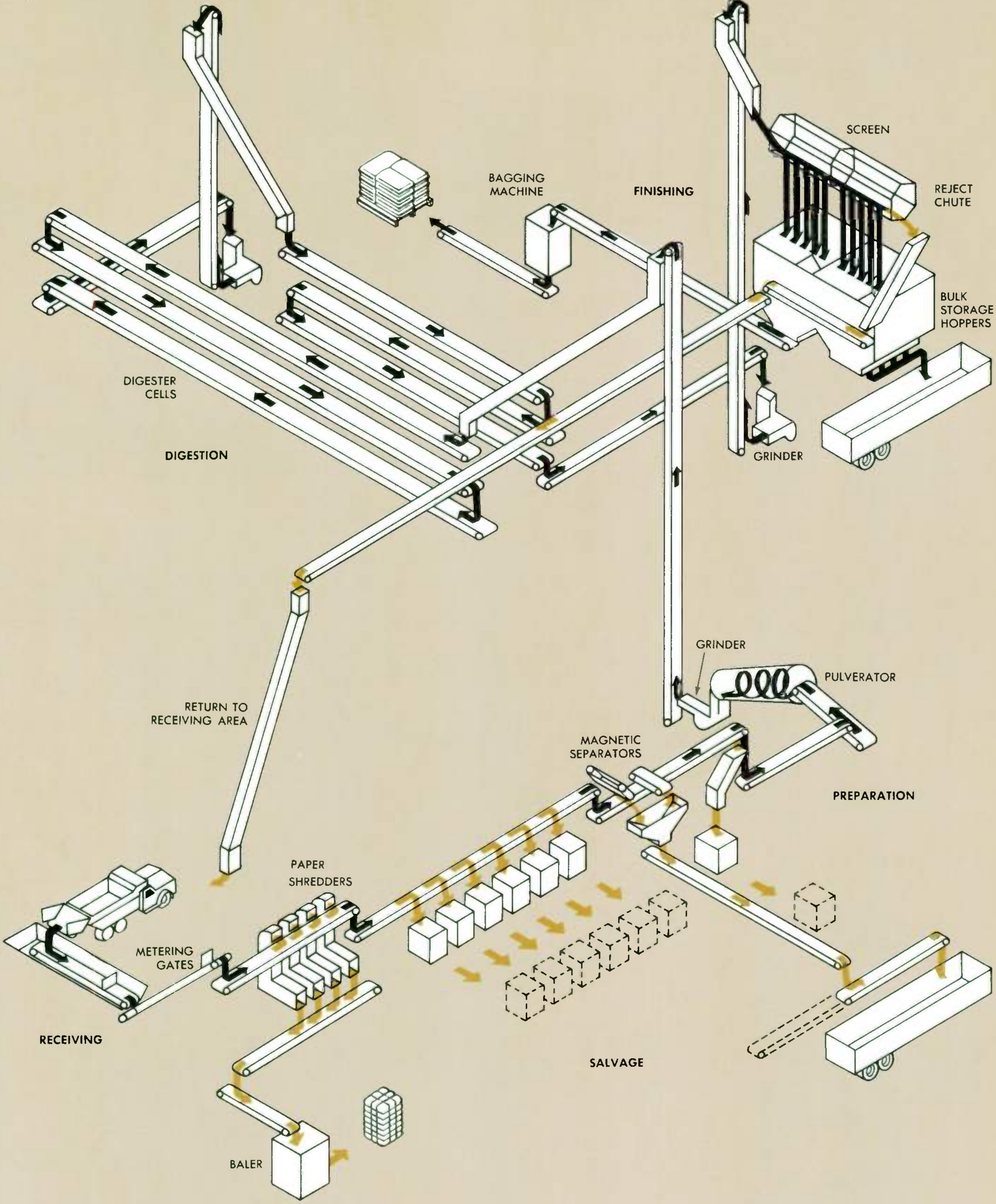

REFUSE RECLAMATION PROCESS begins, at lower left, with the receiving of refuse and the salvage of salable scrap. The remaining material is converted by grinding and by controlled bacterial action into a useful material called compost.

Development of Refuse Reclamation

Composting is widely used in Europe, but the processes employed there are not suitable for the significantly different kinds of refuse produced in this country. European refuse is much denser, containing a larger percentage of vegetable wastes and a smaller percentage of packaging materials. Also, European plants use much hand labor and much of the decomposition takes place in the open; these conditions are generally avoided in this country.

The U.S. Public Health Service has conducted limited pilot studies and laboratory research in refuse disposal, as have several universities. The emphasis with both groups, however, has been on feasibility studies and evaluations of techniques to refine the traditional methods. Virtually no public funds have been provided to develop reclamation processes.

Most of the commercial enterprises that have worked on the development of composting processes adapted to the United States were greatly undercapitalized. Several took an almost entirely mechanical approach and minimized biological decomposition. Others, working with small volumes, developed the biological phase and produced excellent compost but were unable to scale up their processes.

The most successful company in the United States has been Naturizer, Inc., of Norman, Oklahoma. It began its studies with an open pile or windrow system. However, composting in windrows takes six weeks or more, which makes it unfeasible in terms of space requirements for a city of any size. Also, the turning necessary for aeration is expensive, the exposed windrows are influenced by weather conditions, it is difficult to demonstrate that all of the material is subjected to the heat necessary to kill plant and animal disease germs, and the piles of raw refuse could create odors and harbor vermin.

Consequently, the company devised a completely enclosed mechanical system with a closed decomposition chamber and a six-day decomposition cycle. A small pilot plant was put into operation in November 1955. The company then built a plant to process 35 tons (weight of incoming refuse) per day. Facilities were provided for removal and processing of salvage, which decreased the cost of disposal and improved compost quality. This plant demonstrated that the bacteriological and mechanical phases of the method were practical.

Lockheed Aircraft Corporation, under a contract with Naturizer, then designed and built a plant in 1961 to process 150 tons of incoming refuse a day at San Fernando, California. SACS (for *S*alvage *A*nd *C*onversion *S*ystems), Inc., was organized by Lockheed and Naturizer to market reclamation plants. It owns and operates the San Fernando plant, which disposes of all the refuse from the city. Westinghouse designed and furnished the electrical equipment and has maintained an active interest in this plant. Westinghouse also has done the production engineering for later plants and will have primary responsibility for their construction.

A steel apron conveyor at the bottom of the pit starts the refuse through the process. Vertical pit walls, conveyor design, and a metering gate make the material feed through the pit properly.

The metering gate is a vertical steel apron conveyor traveling counter to the flow of material (Fig. 2). It can be shifted to control the amount of material flowing under it, a feature that gives uniform flow even when the pit is overloaded. The gate also tends to even the density of the material.

A conveyor elevates the material to the first picking belt, and a second metering gate on this conveyor further evens the material flow.

Salvage—Approximately 20 percent of the incoming refuse tonnage can be removed and disposed of directly to established markets for paper, rags, metals, rubber, plastics, and glass. Alternatively, all of these items except metals can be processed into compost in areas where markets are not available. To the extent that salvage is removed, of course, the volume of refuse to be disposed of by decomposition is reduced. Also, the return from salvage significantly reduces the cost of refuse disposal.

The salvage section consists of four successive selection conveyors—one for paper; one for glass, rags, plastics, rubber, and miscellaneous metals; one for ferrous metals; and one for aluminum.

The first selection conveyor has four shredders and hoppers for manual segregation of cardboard, newsprint, kraft, and mixed paper. The shredders are special heavy-duty units with hinged blades, since the paper products sometimes conceal pieces of wood and metal. The hoppers below the shredders are unloaded by a collecting conveyor to feed a hydraulic baler.

The second selection conveyor is for manual salvage of rags, glass, plastics, miscellaneous metals, and rubber. Large salvage containers extend well beyond the width of the conveyor on each side. They are on wheels and have special bottoms to permit piggyback mounting on a transfer loader truck. A filled container is simply dispatched to the salvage purchaser and an empty container moved into its place.

A magnetic separator runs across the head (delivery) end of the second selection conveyor, and another runs across the third conveyor (Fig. 3). Any light magnetic metal, such as tin cans, is pulled out of the refuse to fall down a chute and be transported to an automatic can-loading conveyor. This shuttle conveyor is driven back and forth over a truck trailer to load the trailer evenly. (Three hundred tons of refuse normally produce 25 tons of tin cans.)

The third selection conveyor has a magnetic head pulley to salvage heavy magnetic metals. The magnetic pull keeps these objects from dropping onto the fourth selection conveyor; they cling to the belt as it goes around the pulley and then drop down a chute.

Aluminum cans and containers are salvaged along the fourth selection conveyor, in areas where there is a considerable amount of aluminum in the refuse and a market for aluminum scrap.

Preparation—The remaining material is thoroughly mixed and moistened in a pulverator. This is an inclined rotating drum, 26 feet long and 7 feet in diameter, with many triangular plates attached to its inside wall in a spiral pattern. Water is added at the feed end, and the tumbling action mixes it with the refuse and moves the mass through the drum.

Incoming refuse averages about 25 percent moisture. For optimum decomposition, the moisture is increased to about 55 percent. Fortunately, decomposition can be achieved over a wide moisture range—45 to 65 percent. This latitude permits visual determination of the moisture content and use of simple moisture-control devices. The moisture agent may be water or liquid organic wastes such as those produced by packing houses and food processing plants. Sewage sludge is a possible liquid addition with much potential; this is discussed later.

Besides moistening, the pulverator reduces the size of materials, mixes different materials, and smooths the flow to the grinder.

Grinding speeds decomposition by exposing more surfaces for bacterial action. Experience has shown that a special grinder is needed to accept the wide range of materials encountered. The successful grinder that has evolved is an impact type having flails fastened to a rotating shaft by chains (Fig. 4). The flails beat the material, causing it to break up and travel around the inner periphery of the grinder. The ground material flows by air and mechanical action through the grinder and out to the elevator for transfer to the digester.

This type of grinder accepts any material that can flow into the opening—from garbage to cement blocks. It grinds most of this material, and what it cannot grind it passes through without damaging itself. The device grinds the glass and other ceramic materials that remain in the refuse to the consistency of sand. Its inexpensive flails are the wearing parts, and they are easily replaced.

Digestion—The digester consists of six cells, insulated to retain heat. Steel apron conveyors, nine feet wide, move the ground refuse into and through each cell. The cells are arranged in two groups of three—a primary and a secondary section. In each section, the refuse falls off the head end of one conveyor onto the tail end of the next, trapping fresh air for the digestion process.

Each conveyor travels its length in 8 hours, dumping its load to the succeeding section and receiving a new load, and is stationary for 16 hours. (The daily input capacity of the digester is designed for the amount of refuse that the plant can process in one work day. Since there are six cells, digestion is completed in six days.) A grinder between the primary and secondary sections regrinds the material. This grinder and the one that grinds the fully composted material before shipping are flail types, identical to the preparation grinder.

The digester provides a favorable environment for the types of bacteria, molds, and fungi that cause rapid, sanitary, and odor-free breakdown of the refuse. No special inoculants are needed, since the necessary organisms enter with the refuse. The conditions within the digester determine which types of organisms will thrive.

Aerobic (air-requiring) thermophilic (heat-loving) microorganisms are the type desired. They give off only odorless carbon dioxide and water vapor as gaseous by-products, which makes nuisance-free decomposition possible. Also, they produce heat in their metabolic processes and thrive

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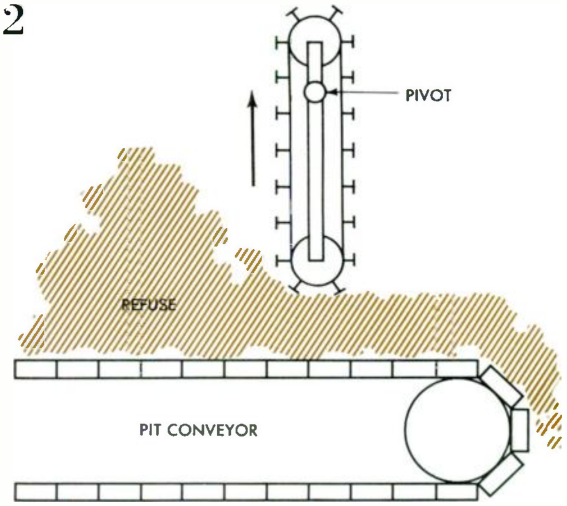
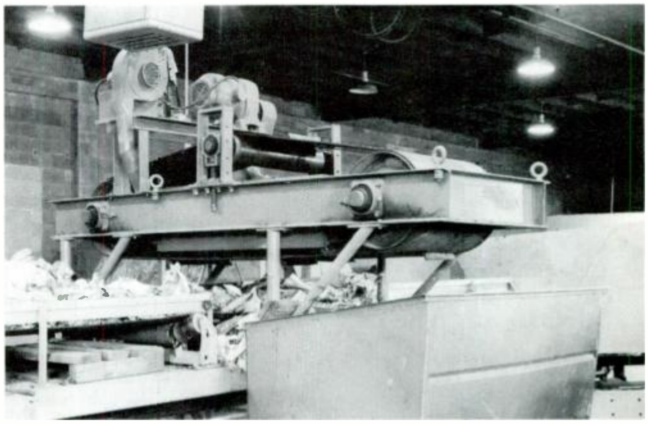
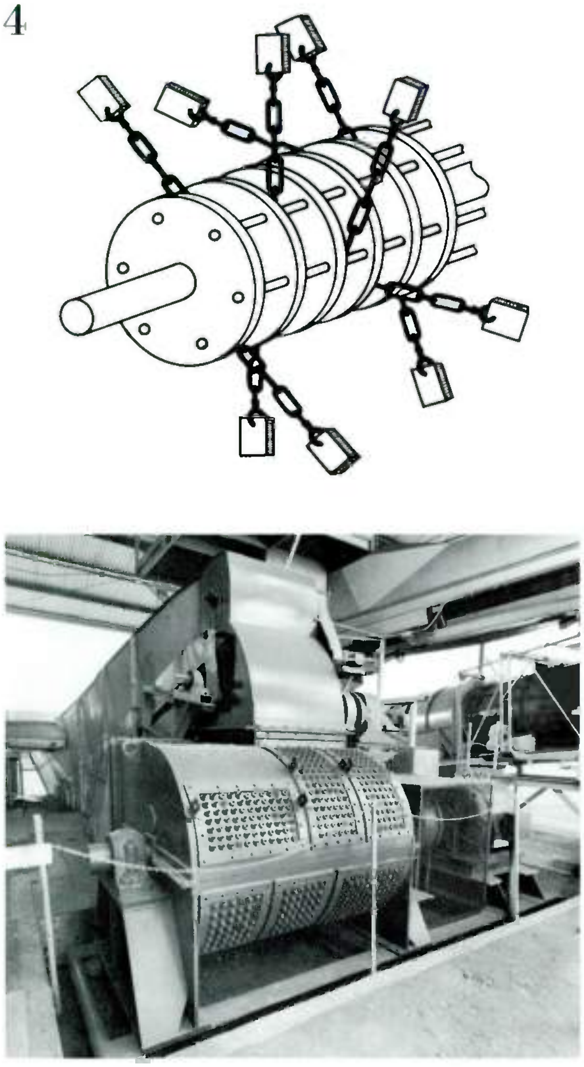


METERING GATES CONTROL FLOW of refuse, which otherwise would be hard to convey. The gate consists of a vertical apron conveyor traveling counter to the flow of material. It is pivoted near the top so it can be swung to regulate the amount of material flowing under it.



3 **MAGNETIC SEPARATORS REMOVE LIGHT MAGNETIC METALS such as tin cans from the flow of refuse. They are short belts running over strong electromagnets and placed at right angles to the refuse conveyor. Cans are pulled out of the refuse by the magnets, are carried sideways past the magnets, and drop into bins or chutes.**

4



SPECIAL GRINDERS ARE USED, since municipal refuse includes such diverse materials as lettuce leaves, wood, and glass. Rotating flails beat the material, and bolts extending through the frame retard the material for thorough grinding. Grinding speeds the process by exposing more surface area to the microorganisms that break the organic refuse down into compost. The unit in the photograph has a capacity of more than 150 tons per shift.

at temperatures that kill all harmful organisms. A temperature of 176 degrees F has been recorded in a digester but, in practice, ventilation is employed to keep temperature under 160 degrees to prevent decrease in activity of the microorganisms. The six-day digestion at this relatively high temperature destroys pathogens (plant and animal disease germs) and weed seeds. No supplementary heat is required.

Other organisms can decompose refuse, but they break the material down more slowly, do not develop the high temperatures required for pasteurization, and give off the foul-smelling gases often associated with rotting organic matter. Fortunately, these organisms do not thrive when conditions are right for the aerobic thermophilic microorganisms. Such conditions are readily maintained by controlling temperature, oxygen, and moisture conditions. Temperature is maintained by insulation on the outside walls of the digester and by the self-insulating qualities of the large volume of refuse inside. Atmospheric oxygen is trapped in the pore spaces of the refuse by the daily dropping from one cell to the next, and the initial grinding is coarse to create large amounts of pore space. Deep vertical cracks form as the material is conveyed within the cells, admitting additional air into the mass. As a result, the desired organisms function with high efficiency.

Finishing—After digestion, the material is ground for the third time. It is then screened to separate fine material from coarser material and to reject items that have not decomposed. The compost is stored temporarily in two hoppers. From there it can be loaded into trucks for bulk sale or bagged for retail sale.

The material that hasn't decomposed—three to five percent of the incoming material—is returned to the receiving area to be recycled or to be hauled to a sanitary landfill. Most of it is decomposed on the second run.

Compost

The final compost product has less than 20 percent of the volume and about 80 percent of the weight of the incoming refuse. It has a chemical analysis of approximately one percent nitrogen, one percent phosphorus, and one percent potash, with the complete range of trace minerals in smaller but significant quantities.

Compost is a source of humus for soil conditioning and is like peat moss, cattle manure, and leaf mold in many respects. It complements, instead of competing with,

5 TYPICAL PLANT COSTS AND REVENUES PER TON INPUT

	Municipal Financing (3½% Interest, 25 Years)	Private Financing (8% Interest, 25 Years)
Cost of Money	$2.16	$3.28
Operating Cost (Average)	4.25	4.25
Plant Cost	$6.41	$7.53
Taxes	(Not required.)	1.00
Profit	(Not required.)	1.00
Total Cost	$6.41	$9.53
Less Salvage	2.50	2.50
*Disposal Fee Required	$3.91	$7.03

**Revenue from compost is not considered because of varying markets.*

chemical fertilizers. The material has a consistent granular texture, so it can be applied mechanically more readily than other organic materials. Its use improves the structure, tilth, and water-holding capacity of soil.

Where it has been marketed, the compost has found ready acceptance by home gardeners, nurserymen, and landscape architects. It also has agricultural value, especially for high crops such as vegetables and orchards. Coarse fibrous compost has been used for starting vegetation and controlling erosion on cut and fill areas. Mechanical application, with seeds and fertilizer where desirable, has proved efficient and effective along roadways in southern California.

San Fernando Plant

This plant can be considered the forerunner of the present generation of reclamation plants. (See *Development of Refuse Reclamation*, page 82.) Its continuous operation since July 1963 has proved the system in practical use. The photographs in this article were made there.

The plant has a receiving and salvaging capacity of 150 tons per shift and a digesting capacity of 50 to 75 tons per day. (The original intent was to compost half of the material after salvage and reduce the remainder to other useful products, but the compost capacity alone has been sufficient to dispose of all San Fernando's refuse.)

Modern electrical equipment minimizes manual operations, and variable-speed drives permit optimum plant operation with varying types of refuse. The drives are controlled from consoles for each section and two master control centers.

Economic Considerations

A refuse-reclamation plant can often reduce a municipality's disposal cost even if the process investment is larger than that for other disposal means. The reason is the revenue from sale of salvage and compost.

A typical plant of 300 tons per day capacity would cost approximately $3 500 000, not including land or site preparation. The cost of money (interest and payment on principal) per incoming ton then could range from $2.16 to $3.28, on the basis of a 25-year payoff at 3½ percent interest and 8 percent interest, respectively. (The first payoff rate is typical of municipal financing and the second of private financing.) Projected operating cost ranges from $4.00 to $4.50 per ton input, depending on local labor and utility rates. Also assume $1.00 per ton for taxes and $1.00 per ton profit if privately financed. Salvage revenue varies with location but, for discussion purposes, it can be figured at $2.50 per incoming ton.

The total plant cost and disposal fee then are as shown in Fig. 5. This figure is meant only to convey a rough idea of the economic considerations. Each case must be studied individually and the costs and revenues worked out.

Planning several plants to make up a total future system is a good approach because it keeps the haul distances for the collecting trucks short. The requirement for a metropolitan area of 500 000 people is approximately 900 tons capacity per day, which could be handled by three plants of 300 tons per day capacity.

With so many factors involved, it is difficult to quote figures to compare costs of refuse-disposal methods. Since hauling and certain collection costs are influenced by the disposal method, these too must be considered.

In general, if a community has nearby sites for landfilling and a standard of operation that meets the approval of health officials and citizens, it is fortunate. This is the least expensive acceptable method, and in these favored areas the disposal cost is as low as $1.00 per ton. For many communities, though, the costs for hauling (national average, $0.15 per ton-mile) to suitable sites becomes the major consideration for this method; for others, lack of land or citizen reaction makes this method unfeasible.

The costs quoted for incineration range from $3.00 to $13.00 per ton. A national average would probably be in the $5.00 to $7.00 range. Installations designed to reduce air pollution and ash residue are the most expensive to build and operate, but they still leave a residue of 20 percent of the incoming tonnage. Residue may run as high as 50 percent; it produces a major hauling problem and can also breed rats and flies in the unburned portions.

The reclamation-plant costs shown in Fig. 5 must be considered with saving of present disposal costs, reduction of hauling distances, and the advantages of nuisance-free disposal that make the cost attractive in some areas even without consideration of potential income from compost. To the extent that markets are developed for the salvage and compost produced, disposal cost is reduced.

The Future

Reclamation as a means of refuse disposal will continue to grow. SACS plants of 150-ton and 300-ton capacity are now operating or designed, and two other standard sizes are envisioned. One, for small towns, would have a capacity of 35 tons a day operated one shift or 70 tons on two shifts. Another, for large concentrations of people, would process 1000 tons a day on one shift and 2000 tons on two shifts.

The major stimulus for development of reclamation plants has been the need to improve disposal means. Now that mechanical reliability has been obtained and a basic plant design developed, the concept can be broadened to treat refuse as a new and untapped source of raw material. A surprising number and variety of products can be developed from it. SACS, Inc., and its associated companies are exploring the production of charcoal, methane, cattle feed, industrial alcohols, wallboard, glass tile, and many other products. Each of these will improve the economics of plant operation.

A process variation with great economic potential is use of sewage sludge as the required moistening agent in the preparation step. Sewage sludge from a given population, with five percent solids, would provide about the right amount of moisture for the size of refuse-disposal plant required to serve that population. Combining the two disposal systems would dispose of another waste material in a useful manner, eliminate the expense of water for the composting process, reduce the cost of the sewage plant by eliminating the concentration part, and increase the mineral and nitrogen content of the compost.

All in all, the concept of reclamation promises to be a force that can reverse the effects of modern urban life that make refuse disposal one of the greatest community problems.

Central Engine-Room Control for Cargo Ships

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Integrated control, automatic equipment operation, and data logging improve reliability and make better use of manpower in new cargo vessels.

American shipbuilders and ship operators have made many technical improvements recently to reduce ship operating costs. These improvements have been mostly in cargo-handling gear, equipment reliability, rust-resistant materials and coatings, navigation aids, increased speed and size, and use of standard containers.

The next major step, central engine-room control, is now being taken. Eight new general cargo ships, the first vessels to be built in the United States with highly automated engine rooms, are under construction. The central engine-room control system in these ships will permit reliable operation of the power plant with fewer people by reducing the number and complexity of operator actions. It does so by placing more operations under complete automatic control, by extending the operator's response with remote control, and by providing him the information needed to detect abnormal situations and take prompt and correct action with assurance. The system also gives officers on the ship's bridge direct control of the speed and direction of the ship's propulsion turbine.

The keel for the first of the eight ships was laid in January this year. Avondale Shipyards, Inc., of New Orleans is building the ships for Lykes Brothers Steamship Company, Inc. Westinghouse is supplying the central engine-room control systems, other electrical equipment, and the main steam propulsion machinery.

The selection and arrangement of the components of a central engine-room control system must be made on the basis of economic factors, especially the type of duty expected of the ship. Since the system engineered for the Lykes Brothers ships is quite complete, it illustrates what can be done.

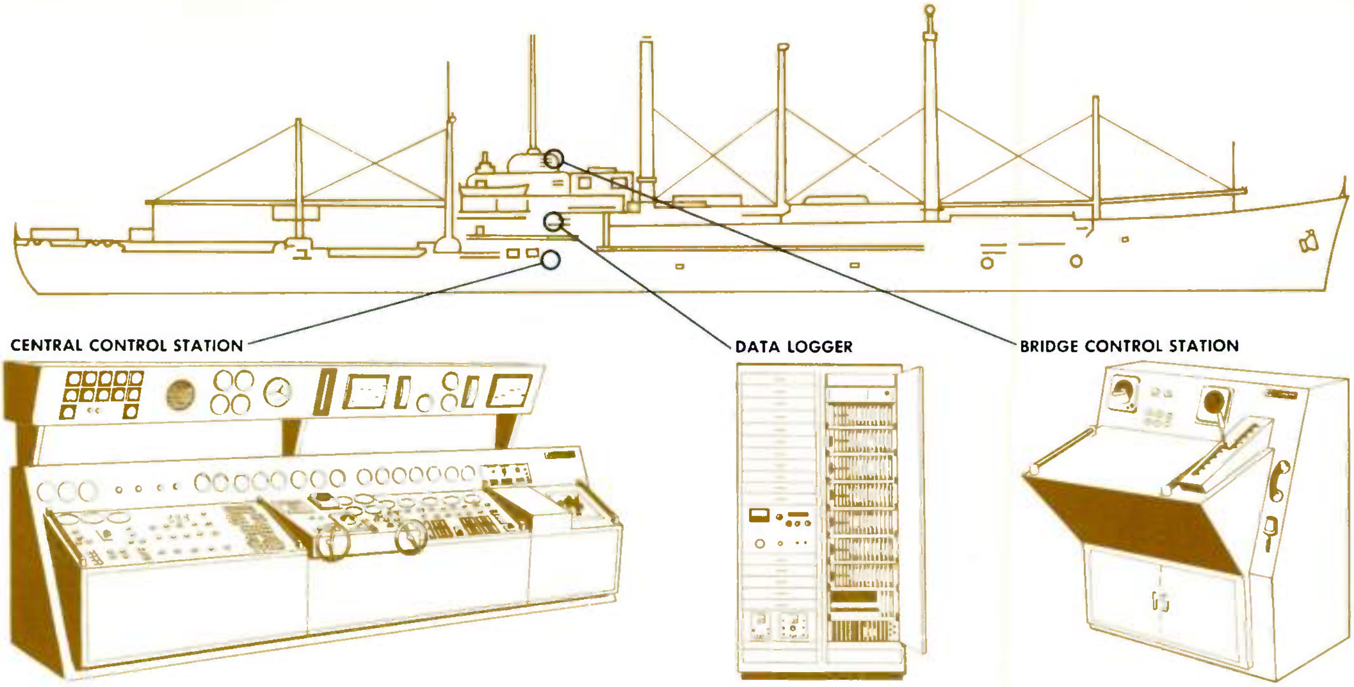
The basic divisions of this system are: *maneuvering control*, with remote operation from the bridge and automatic rate and power-limiting features; *running control* for automatic regulation of such plant processes as combustion without manual adjustment; *central control and instrumentation* for operating and monitoring the plant; *sequence control* for remote start-up and shutdown of components and subsystems; and *automatic logging* of engine-room operational, performance, and historical data.

Maneuvering Control

The propulsion turbine has two modes of control: manual operation from the engine room; and speed-governing control by a propulsion controller, with remote speed and direction setting from the bridge.

In the first mode of operation, the speed and direction of the main turbine are controlled by manipulating maneuvering valves with handwheels on the engine-room console. In the second mode of operation, speed is regulated by an electrohydraulic speed feedback system. (See *Propulsion Turbine Control System,* page 88.) A bridge officer sets the desired turbine speed and direction with a throttle control lever at the bridge control station.

The author acknowledges the important contributions to this article made by R. M. Mentz of Marine Systems Engineering and by L. B. Podolsky of the Marine Products Engineering Department, Lester, Pennsylvania.



CONTROL, MONITORING, AND DATA-LOGGING equipment for propulsion and auxiliary systems in the highly automated cargo vessels will be grouped in three main locations. The central control station in the engine room will enable one operator to supervise and control the main propulsion system and several auxiliary systems. The bridge control station will give a ship's officer direct control of the speed and direction of the propulsion turbine for maneuvering.

The engine room can take over control of the maneuvering valves at any time with the bridge cutout on the engine-room control console. When transferring control from engine room to bridge, interlocks assure that the following conditions are met: both maneuvering valves are closed; both engine-room maneuvering handwheels are set for remote operation; throttle control lever is in *stop* position; *astern* guarding valve is open; and main condenser pump is operating.

Boiler override controls in the propulsion controller protect the steam plant by limiting the rate of opening or the final position of the maneuvering valves if boiler pressure falls below a set minimum or if water level rises above or falls below set limits.

Combustion Control

The combustion control system has sufficient range to permit operation of the plant from stand-by to full-power conditions. It provides efficient performance through a wide range of operations and even for fast maneuvering in a port or other restricted area.

Main steam header pressure is used as an index for controlling the firing rate of both boilers. The output of the steam pressure controller passes through *hand* and *automatic* selector stations, where it is applied as a demand signal for air and fuel. The controller contains proportional and reset functions to enable the control system to maintain a constant steam header pressure.

The selector stations provide several functions. With one station on *hand* and the following station on *automatic*, one-knob remote manual control of the boiler is obtained. Indicating gauges show the loading in the automatic circuit and the manual circuit. The stations have bias-type selector valves, so the relative loads carried by both boilers on automatic can be adjusted, if desired, by the engine-room operator.

Central Control Station

The central control station brings the vital engine-room instrumentation, controls, and alarms together. It is located in the engine room between the main propulsion turbines and the boilers at approximately the center line of the vessel. The station arrangement gives the operator access to the boiler front and a 360-degree machinery viewing zone.

The console consists of a sloping deck-mounted desk with an overhead forward-sloping panel section for operator control and monitoring from a standing position. The forward portion of the desk surface is used primarily for control devices. The rear portion and the overhead section have instrument displays. Controls are located within comfortable and easy reach of the operator, and the display devices within comfortable and easy viewing distance. Related equipment is grouped to give logical meaning to each device and ready association with the controlled components and subsystems. (See illustration at top of this page.)

Significant pressures, temperatures, electrical quantities, and levels are displayed and continuously monitored by independent off-limit detectors and by the data logger. Pressure, temperature, and level indicators use direct-acting gauges or transmitters and receivers, depending on pressure and the fluid being measured. Lighted push-buttons for the remotely operated valves, motor starters, and other devices serve as position or status indicating lights actuated by limit switches or interlocks.

Propulsion-Turbine Control System

The control system, illustrated here in simplified schematic form, includes provision for control of turbine speed and direction from the engine-room console or remotely from the bridge control station.

In remote operation, speed is regulated by a feedback system. A dc tachometer generator, driven by the reduction gearing, provides an electric signal proportional to speed and of a polarity depending on the direction of rotation. The throttle control lever on the bridge moves a multipole switch that selects the proper speed reference voltage with a group of series resistors. The difference between this reference voltage and the tachometer voltage is the speed error signal, which is fed into a speed controller.

The speed-controller output is amplified into a push-pull signal to the torque motors of the *ahead* and *astern* electrohydraulic transducers. The transducers convert the torque-motor force to an oil pressure signal by a cup valve, which is supplied oil from the high-pressure oil system through an orifice. Movement of the throttle control lever in the *ahead* direction causes the control oil pressure from the *ahead* transducer to increase and open the *ahead* maneuvering valve. When the lever is moved to reduce speed, the control oil pressure decreases to allow the *ahead* valve to close. In the *astern* direction of operation, the *astern* transducer increases and decreases the control oil pressure to the *astern* maneuvering valve.

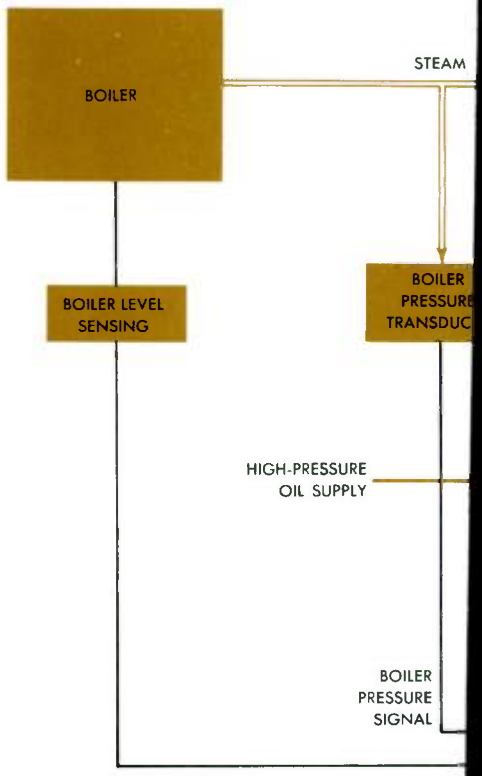
An *astern* guarding valve insures that no steam leaks into the *astern* turbine when the *ahead* turbine is operating, to prevent overheating the *astern* turbine. This valve is tripped open automatically by a solenoid-operated latch when the throttle lever is moved from an *ahead* position to the *stop* position. It can also be operated from the engine-room console and can be closed manually in the engine room.

In the *ahead maximum* position, the throttle control lever sets a reference to the propulsion controller to maintain the *ahead* maneuvering valve in the full open position. The turbine primary steam nozzles give a speed of about 70 propeller rpm (prpm) in this condition. Additional speeds up to 98 prpm are obtained by opening additional turbine nozzle valves manually. An oil impeller on the turbine shaft supplies a hydraulic signal to the *ahead* governor valve to prevent turbine overspeed.

A limit circuit for the speed error signal can be adjusted to limit the opening rate of the maneuvering valves from approximately 5 seconds to 60 seconds. This adjusts maneuvering speed control to boiler response.

In the *stop* position of the throttle control lever, a small reference signal causes the *ahead* valve to open until a speed of less than three prpm is reached. The valve then immediately closes. After the shaft has stopped and a delay of approximately 60 seconds, the operation repeats. This roll-over feature causes the turbine rotor to cool uniformly and thus prevents distortion.

When in *stop* position, a dead-stop switch on the bridge console can be used to stop the roll-over operation by closing both maneuvering valves. Operation of the dead-stop switch causes indicator lights to flash. The engine-room operator then takes control, if tide or current is tending to turn the propeller, to hold the turbines at standstill.



The major groupings of devices and functions included on the console are:

1) Propulsion control group, which contains the main-turbine control handwheels, an engine-order telegraph, a throttle-position indicating system, and the controls and instruments necessary for efficient interaction between operator and control system.

2) Boiler control group, which contains the instrumentation and devices for the combustion control system, feedwater control system, and sequential start-up and shutdown system for the main feed pumps.

3) Turbine-generator group, which contains instruments and devices for sequenced start-up, shutdown, synchronizing, and operation of the ship's service turbine-generator sets.

4) Auxiliary group, which contains instruments and devices for various auxiliary functions such as fire pumps, sea-water service pumps, and auxiliary steam.

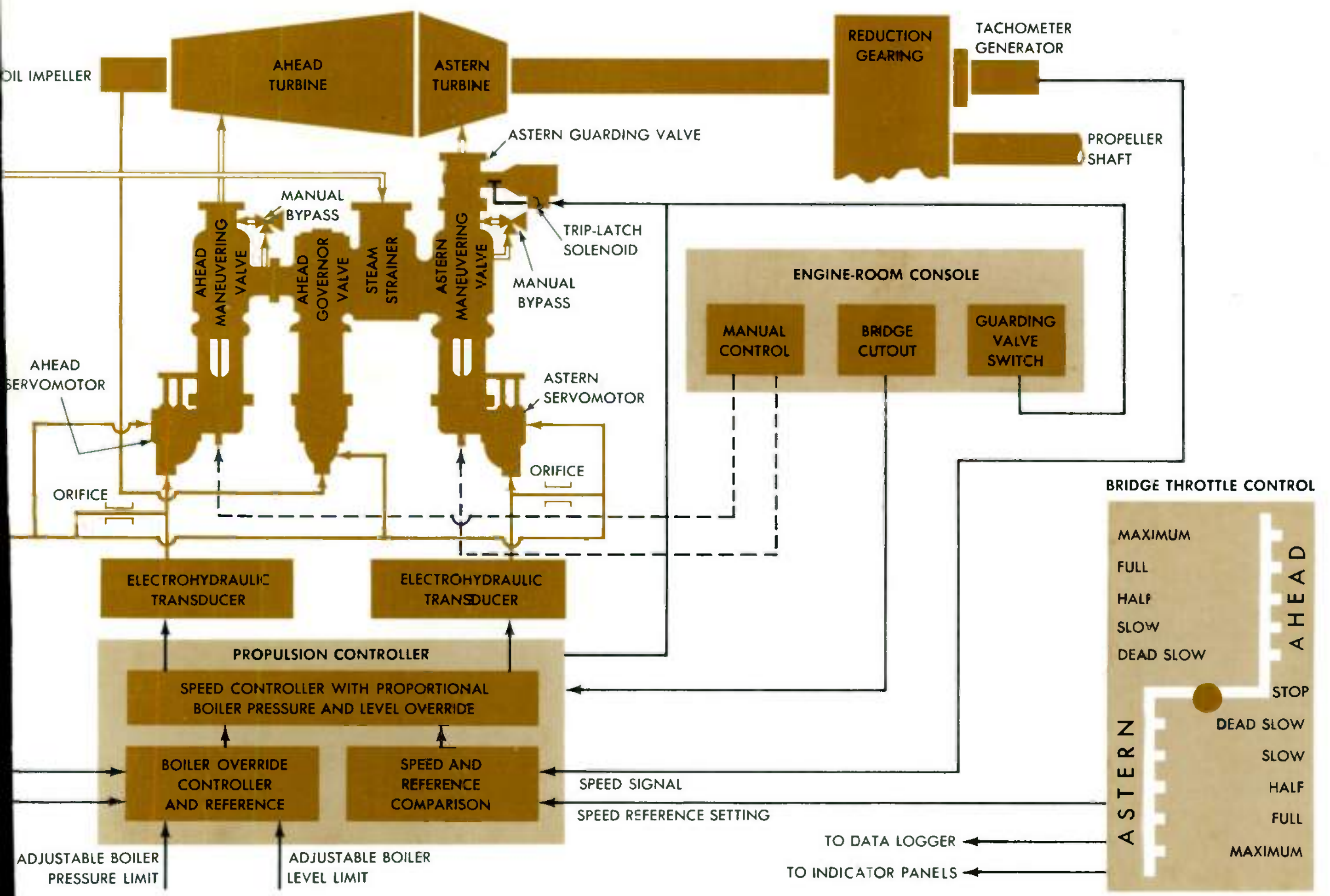
5) Engineer's signal and alarm panel, which provides visual and audible signals and acknowledgment circuitry. The audible signals are an electric howler for emergency and a gong for non-emergency alarms. The panel responds to out-of-range values detected by the logger and the independent alarm detectors. Each alarm circuit causes an alarm light to flash on and off when a trouble signal is received. The light flashes until the audible alarm signal is acknowledged and then remains lit steadily until the off-limit condition has been corrected and the affected system returned to normal.

6) Data logger read-out group, which consists of the logging typewriters, displays, and controls of the data-logging system.

Sequence Control

Automatic sequential operating systems for two service turbine-generators and the two boiler main feed pumps enable an operator to initiate start-up and shut-down from the operating console. Logic elements, relays, and other devices interlock and properly sequence the operations according to a definite program. Sensors supply feedback information that insures proper logic progression. Each system has a series of indicating lights on the console to show the progress and completion of each step or group of steps in the sequence.

Power-operated valves are energized automatically as required to bring the turbine-generator sets from a cold condition to a ready stand-by status, or from an operating to a secured status. Synchronizing and paralleling of the generators and removal of load are controlled manually from the console.



All start-up and shutdown operations can be accomplished manually as well as automatically.

Data Logging

A solid-state, modular, electrically operated data logger is used. The system includes all required sensing elements and transducers, a clock, a performance-log typewriter, and a duplicate typewriter called a bell logger.

The bell logger records the bridge throttle-lever position, telegraph command and reply, and turbine response (ahead or astern rpm) whenever there is a change in bridge throttle-lever position or a change in command transmitted by the engine-order telegraph. This data is typed out on log sheets.

The performance log system scans 100 input quantities from transducers, computes the value of each quantity digitally, and prints out each value. It also prints the date and the time of day at the beginning of each logging cycle. Out-of-range values are printed at the time of occurrence and on restoration to normal.

Input-signal conditioning circuitry insures against degrading of the dc millivolt quantities. Scanning circuitry consists of hermetically sealed relays and solid-state devices to scan the inputs and provide channel programming and identification. The clock is a solid-state digital device.

The data-logging system can compute and print data at the rate of two quantities per second. The total time required for logging 100 analog quantities is 50 seconds.

A switch on the front of the console is used to select the logging interval—15, 30, or 60 minutes. A printing cycle is started automatically at these intervals. Pushing a *demand* cycle pushbutton causes the system to go through one logging cycle.

Any single input channel can be displayed continuously on a digital read-out unit. The operator selects the channels with address switches on the console.

If one typewriter malfunctions, the performance log and the bell log are both printed by the other typewriter. The bell log has precedence over the performance log in printout.

The Future

Most technical improvements in general cargo ships have been evolutionary in nature, with their effects spread over a number of years. Central engine-room control, however, will have a more immediate effect because of its dramatic improvement of ship operation and use of manpower. Virtually all new freighters built in this country from now on can be expected to have a degree of engine-room automation.

Chemical-Shim Control for Nuclear Reactors

P. Cohen and H. W. Graves, Jr., Atomic Power Division, Westinghouse Electric Corporation, Pittsburgh, Pennsylvania.

Use of chemical shim for the control of nuclear reactors offers possibilities for the improvement of overall economics. This possibility is being thoroughly explored today.

As the more basic questions involving operation of water-moderated reactors are resolved, technological concepts that lead to improved nuclear power plant economics become increasingly important. The use of chemical shim in closed-cycle water reactors is such a concept.

Basically, chemical shim involves the use of a neutron absorbing (or poison) material—such as boric acid—dissolved in the primary coolant. By varying the concentration of this boric acid, the poison can be used to control slow changes in reactivity of the core; it can also assist the control rods where intermediate-term reactivity changes (i.e., in the order of hours) are involved.

The use of a dissolved neutron poison as a reactivity control agent is not a new concept. Boric acid has been used to great advantage as a cold shutdown device in the Yankee Atomic Electric Company's Reactor; it was dissolved in the moderator-coolant of several experimental reactors during power operation for brief periods of time; and it was also employed as a reactivity compensation device in the Yankee reactor during power operation. However, there were certain potential problems associated with the use of boric acid as a reactivity shim device during power operation, and these problems have been investigated in detail at Westinghouse for application in several advanced closed-cycle water reactors.

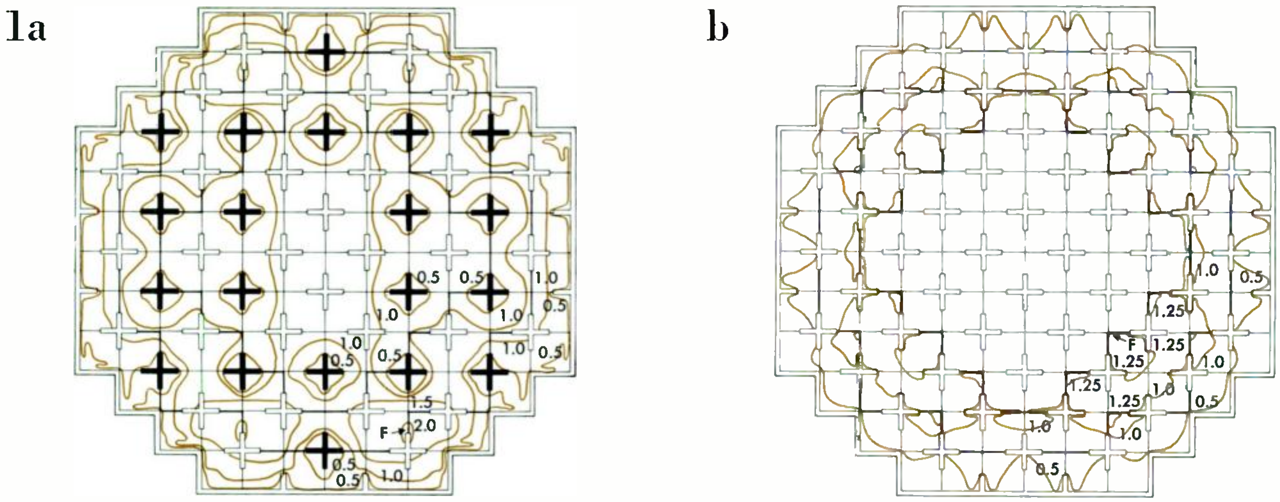
Definition of Chemical Shim—The control requirements of a typical large closed-cycle water reactor can be divided arbitrarily into three categories, according to the rate of reactivity change required. The fast-moving transient requirements and safety shutdown comprise the first category. An intermediate category consists of the reactivity effects of xenon and samarium, plus those due to primary coolant temperature changes associated with reactor heat-up. The third category includes control requirements to compensate for reactivity changes caused by depletion of the original fissionable material, conversion of fertile material, and the build-up of fission products, which occurs over a very long period of time.

Changing the concentration of a chemical neutron absorber dissolved in the primary coolant is inherently a slow process. Thus, the dissolved neutron absorber, by itself, is used only to compensate for such slowly varying reactivity effects as core lifetime, xenon and samarium poisoning, and cold-to-operating moderator temperature change.

Safety Aspects of Chemical Shim—The selective accumulation of boron in the core, as deposits or as absorption on or reaction with other deposits, represented the only significant potential safety problem associated with chemical shim. Any sudden release of accumulated boron within the core to the coolant would cause a rapid increase in reactivity as the coolant containing the released boron leaves the core. The maximum allowable release of such accumulations (or hideout) is calculable in principle, however, for a given core and stated operating conditions.

Earlier in the history of chemical-shim development, inventory control had been considered as a possible means of assuring control of reactivity hazards. Although inventory control is still considered to be a prudent operating procedure that should be observed in a chemical shim plant, analysis shows that after a relatively short period of operation, the accuracy of this inventory is not sufficient for control purposes. By way of illustration, for a typical plant, the maximum allowable release corresponds to a concentration change of only three ppm of boron in the total primary coolant.

In principle, boron hideout can be inferred from a determination of core reactivity. To perform such an evaluation, the reactivity effects and interdependence of fission product poisons, power, temperature, control-rod position, and boron dissolved in the primary coolant must be known. Any reactivity changes that occur, and are not accounted for by the above mechanisms, can then be attributed to boron deposition. It is, therefore, ex-



EFFECT ON POWER DISTRIBUTION is shown in these two cross sections of cores of identical mechanical design. Core at right is controlled by chemical shim; that on left uses control rods to compensate for excess reactivity.

tremely desirable to obtain accurate experimental measurements of the above effects for a variety of core conditions. Unless an experiment is carefully designed to evaluate the effects cited above, it is unlikely that boron hideout or its absence, at the level of concern in a release incident, can be demonstrated positively in reactor operation. If it is assumed, as experience strongly indicates, that only some small fraction of the total amount can come off at any one time, then the allowable amount will be larger and its presence (or absence) more readily demonstrated.

A detailed investigation of hideout has been conducted in the Saxton Reactor after a thorough investigation of the interrelationships of the significant core reactivity parameters. The flexibility of the Saxton Reactor, which has been designed for both power production and experimental work, permitted an accurate evaluation of boron hideout. Saxton has been operated for 160 days with approximately 1000 ppm boron, with and without nucleate boiling in the core. No boron hideout has been detected in any chemical shim operation to date within the accuracy of the nuclear measurements.

Core Design Considerations

The major gains from the use of chemical shim are in the areas of core design and performance. When employed with multiregion or with cycled-fuel loading, chemical shim permits improved core performance through reduction in the ratio of maximum to average power density. As a result, many more fuel assemblies can operate closer to their thermal design limits. A reduction in mechanical (rod) control requirements permits increased flexibility in fuel-assembly mechanical design and in cheaper or fewer control-rod drive mechanisms.

Increased Power Density—Chemical-shim control permits a reactor to be operated at full power in the steady state condition, with all control rods located in the optimum position for load-change transients and trimming of power distribution. Since the distribution of neutron poison is uniform and is independent of the amount of reactivity being controlled, the fuel loading distribution is much more easily "designed" to yield a uniform power distribution. For example, the density of fissionable material may be distributed in concentric zones about the axis of the reactor to maintain a very favorable power distribution, and local power peaking effects caused by control rods are minimized.

These effects are shown in Fig. 1 with a 120-fuel-assembly core loaded in three concentric regions in a large pressurized water reactor. Each region contains 40 fuel assemblies. The region boundaries are represented by darker lines than those outlining fuel assemblies, and control rods are represented by black cruciforms. The unfilled cruciforms contain UO_2-bearing fuel rods having an enrichment appropriate to the surrounding fuel. The core cross-section on the right shows the power contour map through a transverse section of a core controlled by a uniform chemical poison. The cross-section on the left shows an identical mechanical design in which neutron-absorbing control rods are used to compensate for roughly six percent excess reactivity.

The major disadvantage of controlling solely by rods is that the optimum fuel-loading distribution with one control-rod pattern may be far off the optimum power density for other patterns. A control-rod program specification, however, requires that an acceptable power distribution be achievable with multiple control-rod patterns to suit the varying excess reactivity requirements of the core throughout its life. The control-rod pattern at the left of Fig. 1 is representative of the worst transverse power distribution that might be obtained with an optimum control rod program and is equivalent to a maximum-to-average power density ratio of 2.5. This is a 50 percent increase over the maximum-to-average ratio shown on the right side of the figure.

Cycled Fuel Loading—Chemical-shim control is well suited to reactor cores that employ the fuel cycling concept. A "cycled" reactor is a multiregion reactor in which fresh fuel is loaded in one set of fuel assembly positions of the core, with the other fuel assembly positions being occupied by fuel at varying stages of depletion. Loss of neutrons to control poison is thus minimized in a high burn-up reactor by balancing the high excess reactivity of fresh fuel with low or negative excess reactivity of highly burned fuel. Most of the loss in neutron economy associated with a batch-loaded core (of the same burn-up) is eliminated through the fuel-cycling concept. In a multiregion reactor employing chemical shim, fuel assemblies at various stages of depletion are distributed in such a manner that the maximum-to-average transverse power density is minimized.

Reduced Control-Rod Requirements—In a chemical-shim-controlled reactor, the control-rod requirements are reduced by more than a factor of two. The core designer may take advantage of this reduction in any one of several ways. For example, the number of control rods can be reduced. This simplifies the core and vessel design, and reduces the expense involved in providing the full complement of control rods, control-rod mechanisms, and their associated instrumentation. The size and "blackness" (absorption) of control rods, or both, can also be reduced, thus permitting less expensive control materials. (For example, ordinary stainless steel could be used in lieu of Ag-In-Cd, Hf, or boron stainless.) Performance requirements and economic factors of the design under consideration, of course, dictate which path should be followed.

Moderator Temperature Coefficient—One possible limitation on the use of chemical shim in closed-cycle water reactors is the effect of the poison on the moderator temperature coefficient. Since water density decreases with an increase in temperature, the poison density also decreases. This gives rise to a positive component of the moderator temperature coefficient directly proportional to the poison concentration, as is illustrated in Fig. 2. This figure shows the relationship between the moderator temperature coefficient and boron concentration in the Yankee Atomic Electric Company's reactor. The relationship shown was obtained experimentally in the core at operating temperature and zero power during the start-up experiment program. Since all points were obtained in a critical reactor, where boron is exchanged for control rods, the slope of the curve indicates the sum of the boron effect, and the effect of the removal of control rods.

No safety problem exists in a UO_2-fueled closed-cycle reactor as long as the moderator coefficient is not too strongly positive, since the fuel temperature coefficient is strongly negative. From a control standpoint, however, a negative moderator coefficient is considered desirable, since it permits more flexibility in establishing control set-points for an automatic coolant temperature control system. The least negative coefficient occurs in the zero power core at the beginning of the fuel cycle, becoming more negative as fuel burn-up proceeds. This reduction in negative temperature coefficient due to a dissolved neutron poison does not currently appear to impose a limit on fuel burn-up.

Chemistry Aspects

Before its application in current water-reactor design, any chemical shim agent must first be demonstrably safe. Secondly, its indirect costs due to new limitations on the plant design, or its conceivably adverse effects on plant performance, must not subtract substantially from gains obtained in core design and performance. Studies led to the conclusion that boron, in the form of boric acid homogeneously distributed in the moderator coolant, provided the optimum application of chemical shim for water moderated and cooled power reactors. The application appeared to be sufficiently feasible to justify the design of a large power reactor for such operation, subject to the demonstration that:

1) The selective accumulation of boron in the core (as deposits, absorption on crud, incorporation in corrosion films) would not be great enough to introduce the possibility of causing sudden unacceptable reactivity changes.

2) The presence of boric acid would not, of itself, adversely affect core fouling, corrosion, or wear of materials, or prohibit such effects from being controlled by the addition of acceptable amounts of alkali.

3) The presence of boric acid would not, of itself, significantly increase corrosion product release from core cladding, with consequent plant contamination; or prohibit such effects from being controlled by the addition of acceptable amounts of alkali.

4) Currently employed means of purification and waste disposal, with only minor modifications, would be suitable for the required coolant processing.

A program to this end has been largely completed at Westinghouse.

Safety—An appropriate chemical study of the boric acid-water-corrosion product system provides a deductive definition of the safety problem. A two-fold program to this end has been completed at Westinghouse: (a) measurement of the physicochemical properties of solutions of boric acid and the alkali borates; and (b) meas-

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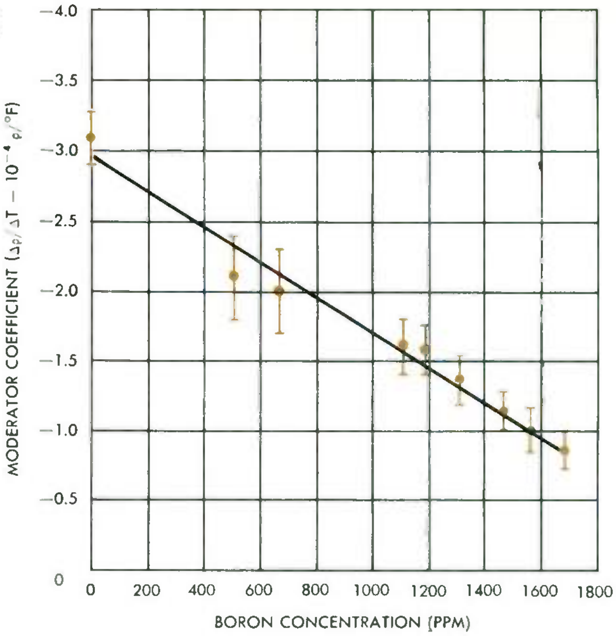

EFFECT OF BORON ON MODERATOR TEMPERATURE COEFFICIENT is indicated here. Information for this curve was obtained from experiments in the Yankee reactor, at operating temperature and zero power during start-up.

urements of the interaction of boric acid and alkalized boric acid with fuel, corrosion products and heat transfer surfaces at a variety of conditions, including in-pile tests fully simulating plant operation. The measurements made have provided a basic understanding of the nature of borate solutions at high temperatures. As noted above, the full cycle of reactor operation is being tested in the Saxton Reactor (in the General Public Utilities System), which has a full complement of control rods.

The program to determine the effects of various parameters on the hideout of boron in reactors included the following:

1) Determination of the absorption of boron by synthetic corrosion products and corrosion films via out-of-pile testing under isothermal conditions.

2) Tracer experiments to measure concentration effects of heat transfer and clean and dirty surfaces.

3) Determination of the absorption of boron by synthetic corrosion products under irradiation at low and high temperatures.

4) Measurement of the kinetics of boron absorption and desorption on synthetic crud, out-of-pile physical and chemical characteristics of reactor crud, and comparison with synthetic preparation.

5) Measurement of permanent pick-up of boron on natural crud as a result of long-time irradiation at high temperatures.

6) Reaction of boron with UO_2.

Laboratory tests to date have not demonstrated any significant hideout of boron for anticipated reactor operating conditions. The Yankee tests in Cores I and II showed an apparent loss of reactivity and a reactivity gain, respectively. These observations are believed to be manifestations of the Yankee pH effect, whereby increase of pH (i.e., increasing alkalinity) is found to increase reactivity, and not due to boron hideout. The Saxton chemical-shim experiment operation, mentioned earlier, will continue for over a year to demonstrate whether or not there are any long-term problems involved.

Selection of Materials—The performance of mechanical components of the plant may be adversely affected by corrosion and wear. It was essential, therefore, to determine whether materials normally employed are compatible with boric-acid solutions, or if suitable substitutes were required. Considerable corrosion information on boric-acid already existed, and tests at Westinghouse and elsewhere have shown that most materials that are satisfactory in neutral or high pH water are also suitable for use in boric-acid solution at high temperature.

Typical materials of construction have been subjected to long-term corrosion tests in out-of-pile loops. Galvanic corrosion problems have already been investigated by measurement of corrosion and galvanic current in high-temperature autoclaves. In addition, core components, including simulated fuel rods and holders, have been tested out-of-pile under fully simulated heat-transfer conditions for both sub-cooled and bulk-boiling conditions, and without any observable adverse effects.

Possible fouling of core surfaces by deposits of corrosion products merited further investigation; some tests showed that although such deposition is relatively high from boric-acid solutions, it may be reduced by the addition of alkali. For this and other reasons, the Saxton program investigated this question.

Accessibility—Corrosion of core materials and deposits of corrosion products constitute the two main sources of induced activities responsible for radioactive contamination of plant components, with consequent reduction in plant accessibility. Corrosion-product release and deposition under irradiation are both materially reduced by increasing the pH of the coolant. To evaluate the problem and the possible need for alkali addition, measurements have been made of corrosion product release from 304 stainless steel in boric acid, with and without alkali additions. Irradiated samples were corroded for a period of several months. The total quantity of material released was then determined by decontaminating the loop and measuring the total activity released to the system. Relative contamination of different materials also was ascertained. These tests have been completed and the technique appears to be quite satisfactory. Although release rates with alkali addition were higher initially than those with pure boric acid, subsequent rates were significantly decreased.

Purification and Waste Disposal—Purification by ion exchange is provided in water cooled and moderated reactors to assist in controlling radioactivity formed by neutron capture on materials of construction, and to control fission-product activities that may be released from failed fuel elements. Since boric acid is intrinsically a weak acid, the exchange of foreign ions is quite favorable on borate form exchangers exposed to boric-acid solutions. To provide design data for such exchangers, measurements were made of those parameters that determine ion bed performance. If alkali is added to the boric acid, exchange performance is not as good as with pure boric acid; but it is at least of the same order as that occurring with base form exchangers exposed to water containing small amounts of alkali.

The major quantities of effluent in a plant arise from heat-ups following cold shutdown. The cold shutdown poison must be removed by feed of pure (or purer) water. Actually, the quantities of fluid processed for the same number of shutdowns and start-ups will be lower for a chemical-shim plant than for a plant that uses chemical poison for hot-to-cold criticality control alone. This is because the average ratio of initial (cold) to final (hot) poison concentration, which is a measure of the solution required, is less for a chemical-shim plant.

In principle, effluent fluid can be recycled to minimize overall process requirements. However, since the process plant must, in effect, be designed for end-of-life (maximum dilution required), it will always be possible to process all effluent by evaporation and then recycle pure water. Where the opportunity presents itself in operation, effluent will be recycled.

Summary

Chemical shim with boric acid or alkalized boric acid offers substantial physics advantages in closed-cycle water reactor design and performance. Chemistry studies and reactor operating experience to date have shown favorable results.

Westinghouse
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NOTE: Work reported in this paper was carried out for the Atomic Energy Commission New York Operations Office under AEC Contract AT(30-1)-3064.

Ultrapure Metals and Alloys

Heinz G. Sell, *Metals Research Section, Lamp Division, Westinghouse Electric Corporation, Bloomfield, New Jersey.*

Better understanding of the nature of many metals and alloys depends upon the availability of ultrapure samples. A new method is especially suitable for producing high-purity tungsten and other high-temperature metals.

The properties of a given metal often undergo dramatic changes as the purity of the element or alloy is increased. For example, refractory metals such as tungsten or molybdenum, which are normally brittle at low temperatures and difficult to work in commercial purities, become ductile over a wide range of temperatures if their impurities are lowered to a few parts per million or their structure changed to that of a single-crystal matrix.

These facts have already been well exploited in the case of semiconductor materials, but much has yet to be learned about the effects of extreme purity on most high-melting-point metals, or, conversely, the effect of controlled amounts of impurities.

A basic first step is to prepare ultrapure elements and alloys both for study of their properties and for experimentation in their practical application. Of particular importance are elements and alloys of high melting point, which are of major importance in applications ranging from light bulbs to space engines.

A new method, originally conceived in England and further developed at Westinghouse, produces tungsten of ultrahigh purity, either in single crystal or polycrystalline form. It has also been used to purify many other high temperature metals or alloys. The process involved is called electron-beam floating-zone purification.

The Principle of Floating-Zone Purification

Purification by zone refining is a technique that has been used for many years, particularly for purifying semiconductor materials. Basically, it consists of passing a rod to be purified through a heater at a controlled rate of speed; the temperature of a short segment of the rod is maintained at a high enough value to form a molten zone in the rod, which is moved from one end of the rod to the other as the rod moves through the heater. Most impurities tend to remain trapped in the molten zone and are thus moved through the rod to one end, where they can be cut off. Induction heating is frequently used as the source of heat for this process.

In approach, electron-beam floating-zone purification is similar, except that the heat is produced by electron bombardment of the rod, which must be arranged in a vertical position, rather than by induction heating (Fig. 1). However, the purification mechanism is quite different, primarily because melting must be carried out in a vacuum at a pressure of less than approximately 1×10^{-3} mm Hg. At higher pressures, gas molecules interfere with the electrons by collision, and energy is transferred to the gas instead of to the metal rod to be melted.

The most effective mechanism involved, therefore, is vacuum distillation. As the metal melts, impurities then evaporate or tend to form tiny bubbles in the molten portion of the rod (Fig. 2); these bubbles join with others and eventually reach a critical size, at which time they erupt from the surface of the rod. After enough impurities have been removed by this bubble elimination process, there are no longer enough impurities left to form a bubble of critical size; from this point on the mechanism of purification is called bubble transport. Bubbles merge into one large bubble and this moves through the rod with the molten zone and eventually is deposited at one end of the bar. The third mechanism is zone refining similar to that used for materials with lower melting points; however, in the case of refractory metals, this contributes very little to the purification process.

In addition to purification, single crystals can be grown by the same technique. In effect, this process is similar to that of drawing semiconductor crystals from a molten pool; the molten zone of the rod is comparable to the molten pool, and, therefore, a single crystal can be "grown" by this technique. Since the force that holds the molten zone suspended between the two solid sections of the rod

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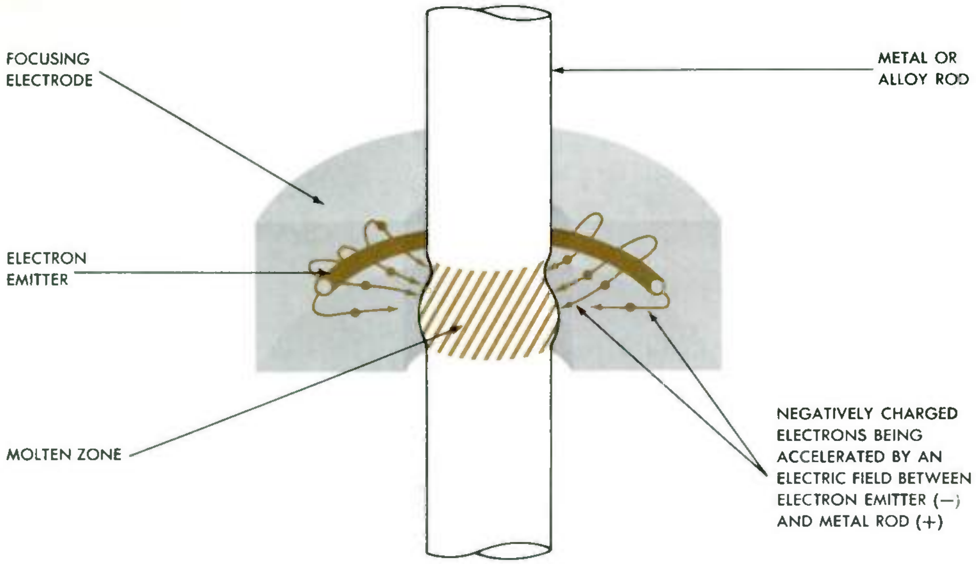

ELECTRONS BOMBARD THE METAL ROD and thereby heat a small zone to the molten state. Electrons are emitted from a filament and accelerated by an electric field to strike the positively charged rod. Surface tension supports the molten zone.

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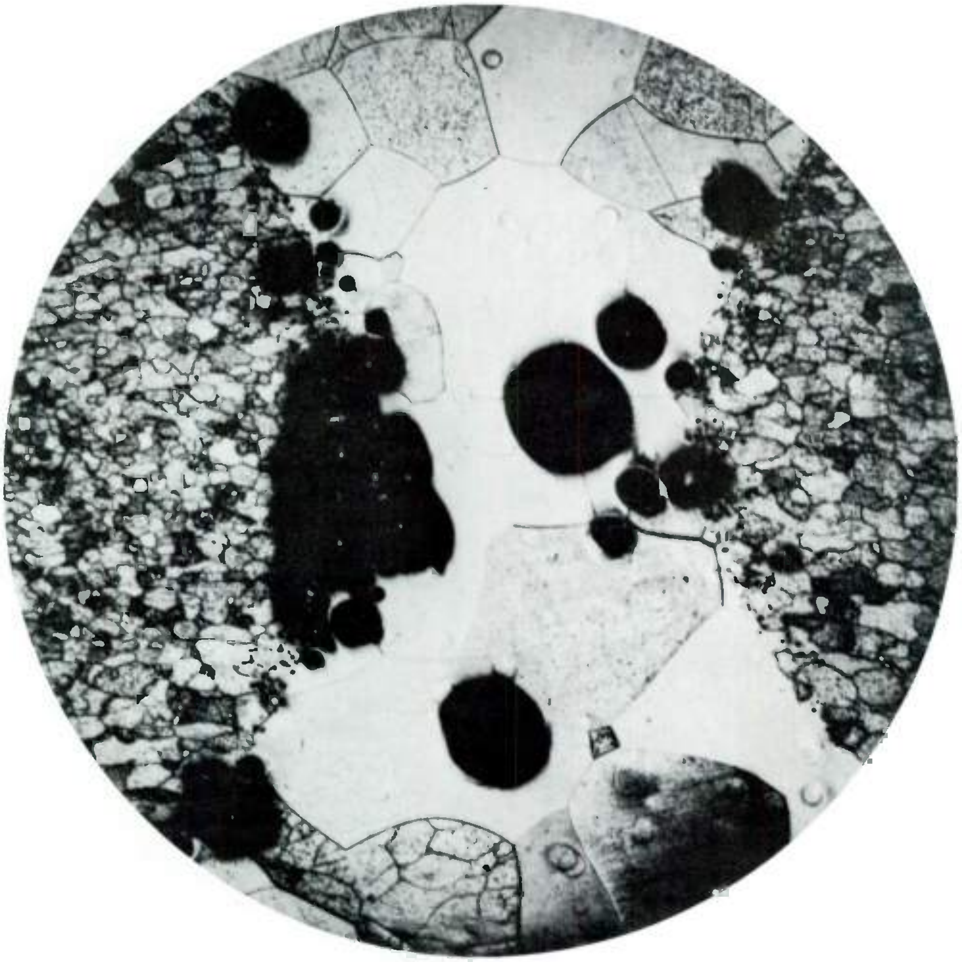


AS THE MOLTEN ZONE FORMS, the grain structure begins to disappear. Bubbles of impurities in gaseous form begin to form along grain boundaries. The bubbles appear as black spots. As the process proceeds, the bubbles join to form larger bubbles, an important mechanism in purification. This photo was taken after heat had been applied for about 15 seconds.

3 EFFECT ON PURITY AND YIELD STRENGTH OF TUNGSTEN

Material	Residual Resistance Ratio R(273°K)/R(4.2°K)	Impurities in Solution Atom % ppm	Yield Strength at Room Temperature—Psi
Powder Metallurgical W	84	655	—
W—1 Melting Pass	10 000	3.7	100 000
W—5 Melting Passes	40 000	1.4	60 000
W—Ultrapure	80 000	0.7	—

is the surface tension of the molten metal, the molten zone is limited with respect to length and diameter. Experience, especially with tungsten, molybdenum, and tantalum, shows that a single crystal can be grown without difficulty in 0.300-inch rods of these metals. The largest diameter crystal was a tungsten crystal 0.350 inch in diameter. In general, crystals of these large diameters are not grown routinely, since power requirements become excessive and purification is slowed down.

Purity of Floating-Zone Melted Metals

A number of analytical techniques are employed to determine the actual purity of zone-melted crystals. In addition to standard analytical techniques like emission spectrography, vacuum fusion, and chemical analyses, residual-resistance-ratio determinations and solid-source mass spectrometry have been used recently. Mechanical tests and the measurement of physical properties are also evaluated extensively to find an answer to the rather difficult question—how pure are these crystals?

Recent mass spectrometric results have shown that with the exception of carbon, impurities are reduced by zone melting by 10 to 1000 times. The total nongaseous impurity content amounts to less than approximately 6 atom ppm. Most affected are metallic impurities, which are reduced to the 0.1 ppm level or even lower.

This is confirmed by residual-resistance-ratio measurements. The residual-resistance ratio is a measure of impurities in solid solution.

Among the factors that contribute to the total electrical resistance of a material are a thermal component (R_{TH})—due to thermal agitation of the atoms—and an impurity component (R_i)—due to impurities in the material. The thermal component is virtually nonexistent at absolute zero, and increases with temperature. The impurity component, on the other hand, is relatively constant over a wide temperature range.

If the total resistance is measured at both the freezing point of water (273 degrees K) and at the boiling point of liquid helium (4.2 degrees K), the following ratio, called the residual-resistance ratio, can be formed:

$$r=\frac{R(273^\circ\ \mathrm{K})}{R(4.2^\circ\ \mathrm{K})}$$

The higher the ratio, the lower the impurity content. Data for tungsten is given in Fig. 3 together with yield stress values of the respective crystals.

Properties of Ultrapure Metals and Alloys

The properties of the ultrapure metals also provide an indirect check on the purity of these materials.

Mechanical Properties—Most striking is the effect of purity on the ductility and the temperature dependence of the yield strength of tungsten. High-purity polycrystalline tungsten is completely brittle at about 200 degrees C while single-crystal tungsten is very ductile at this temperature and even exhibits ductility down to −196 degrees C. Since the ductility of single crystals depends on orientation, substantially higher ductility is obtained on crystals stressed along a certain direction. The temperature dependence of the yield strength, as is evident from Fig. 3, is greatly reduced in tungsten crystals passed through the refining cycle five times, as compared to crystals that have undergone but one pass. These results were obtained on earlier crystals, which were not as pure as those produced today.

Unique and controlled properties can be achieved in these ultrapure metals and alloys by purposely contaminating and heat treating them. For instance, internal carburization or oxidation are most useful approaches and have been thoroughly studied. Single-crystal alloys of superior strength can be produced by this technique.

Another characteristic of the ultrapure metals is that, by appropriate processing, they can be worked into smaller diameter rod or into wire while retaining their single crystallinity. This was also demonstrated on tungsten. Finally, ultrapure zone-melted metals and alloys can be reprocessed into powder and used commercially as base materials for larger or odd-shaped structures that must be very pure because of environmental conditions.

Physical Properties—Such ultrapure metals and alloys have a great impact on fundamental research, because they furnish the materials for studies that could not otherwise be made. In effect, such metals are "new" materials, since their properties are often quite different from those of less purity; thus scientists have whole new areas of investigation open to them.

Through studies such as these, a better understanding of the electronic properties of metals and alloys is being developed.

Beyond these studies lies the field of commercial applications in the form of new materials with very characteristic properties, like ultrapure tungsten filaments in vacuum gauge tubes or superconducting alloys.

While much progress has been made, more can be expected. A new and radically different electron-beam floating-zone melting furnace is under construction incorporating improvements learned in the use of the equipment described here. The crystals that will eventually be produced are expected to be far more perfect and considerably more pure than the materials available today.

ABOUT THE AUTHORS

H. W. Lydick, a field application engineer, and *J. F. Sutherland*, a design and development engineer, join forces in this issue to describe the first ADDAPS system application.

Lydick joined Westinghouse in 1947 after graduation from Montana State College (BSEE). After his graduate student course assignments, Lydick went to the Salt Lake City office as a sales assistant. He was made a sales engineer in 1949, and a service engineer in 1951. He moved to the Los Angeles office as a consulting and application engineer in 1953, and then to the Phoenix office as a district engineer in 1956. For the last eleven years, his major responsibility has been application engineering of both industrial and electric utility apparatus and systems.

Sutherland came with Westinghouse from the University of Missouri (BSEE) in 1955, but went almost immediately to the U. S. Air Force. He returned to Westinghouse in 1959. After attending the company's advanced design school, he was assigned to the new product laboratory as a member of the Prodac computer task force. He moved to the Electric Utility Control Systems Department in 1962 to work on frequency-control equipment. A year later, he was made project manager of the ADDAPS system being developed for Arizona Public Service. He is presently working on the development of small computer systems for industrial and electric utility control applications.

H. G. Furlow is assistant to the president of SACS, Inc., the organization that markets the reclamation plants described in this issue. A native Oklahoman, he entered the University of Oklahoma in 1946 after service in the U. S. Navy in World War II. He received his BA in 1949 and his MA in 1950 in clinical psychology.

During the Korean conflict, Furlow was recalled to Navy service for a year and a half. He then joined Field Enterprises, an educational book publisher, as a salesman and soon became a district sales manager. He returned to the University of Oklahoma in 1953 and completed the course work required for a PhD in psychology. He was one of the original organizers in 1954 of Naturizer, Inc., the company that developed the basic processes used in the refuse reclamation systems.

Furlow's coauthor, *H. A. Zollinger*, is a prolific writer whose latest article in the *Westinghouse ENGINEER*—"Mechanized and Automated Warehousing"—appeared in the January 1964 issue. His career has been mainly in the engineering of material-handling drives, controls, and systems. He joined Westinghouse on the graduate student course in 1951, was assigned to the material-handling section of the industrial engineering department, and is now in Material-Handling Systems, Industrial Systems Divisions.

Zollinger graduated from Michigan College of Mining and Technology in 1951 with a BS in electrical engineering. He earned his MS in electrical engineering at the University of Pittsburgh in 1958 and a business and management certificate there in 1961.

R. E. Stillwagon has been in charge of the advanced development group, Marine Systems Engineering, since 1960. He is responsible for development of new products and advanced systems for the marine industry, including shipboard mechanization and automation. An outgrowth of this work is the central engine-room control system for cargo ships.

Stillwagon joined Westinghouse in 1946 on the graduate student course after graduating from Worcester Polytechnic Institute with a BSEE degree. He was assigned to the railway equipment group, where he designed diesel-electric locomotive propulsion systems and control devices. In 1955, he was made senior programmer in a task force that set up computer operations in the data-processing department at the East Pittsburgh works. He joined the marine and transportation engineering department in 1956, where he was responsible for application engineering and propulsion system design.

J. L. Blackburn graduated with high honors from the University of Illinois (BSEE) in 1935, and came with Westinghouse on the graduate student program in 1936. He moved immediately into relay engineering and has been associated with application of relay systems since. He is presently engineering section manager responsible for relay application and systems, advanced development and relay digital instrumentation.

Off the job, Blackburn spends a considerable portion of his time teaching. He is an Adjunct Professor at the Polytechnic Institute of Brooklyn and at the Newark College of Engineering.

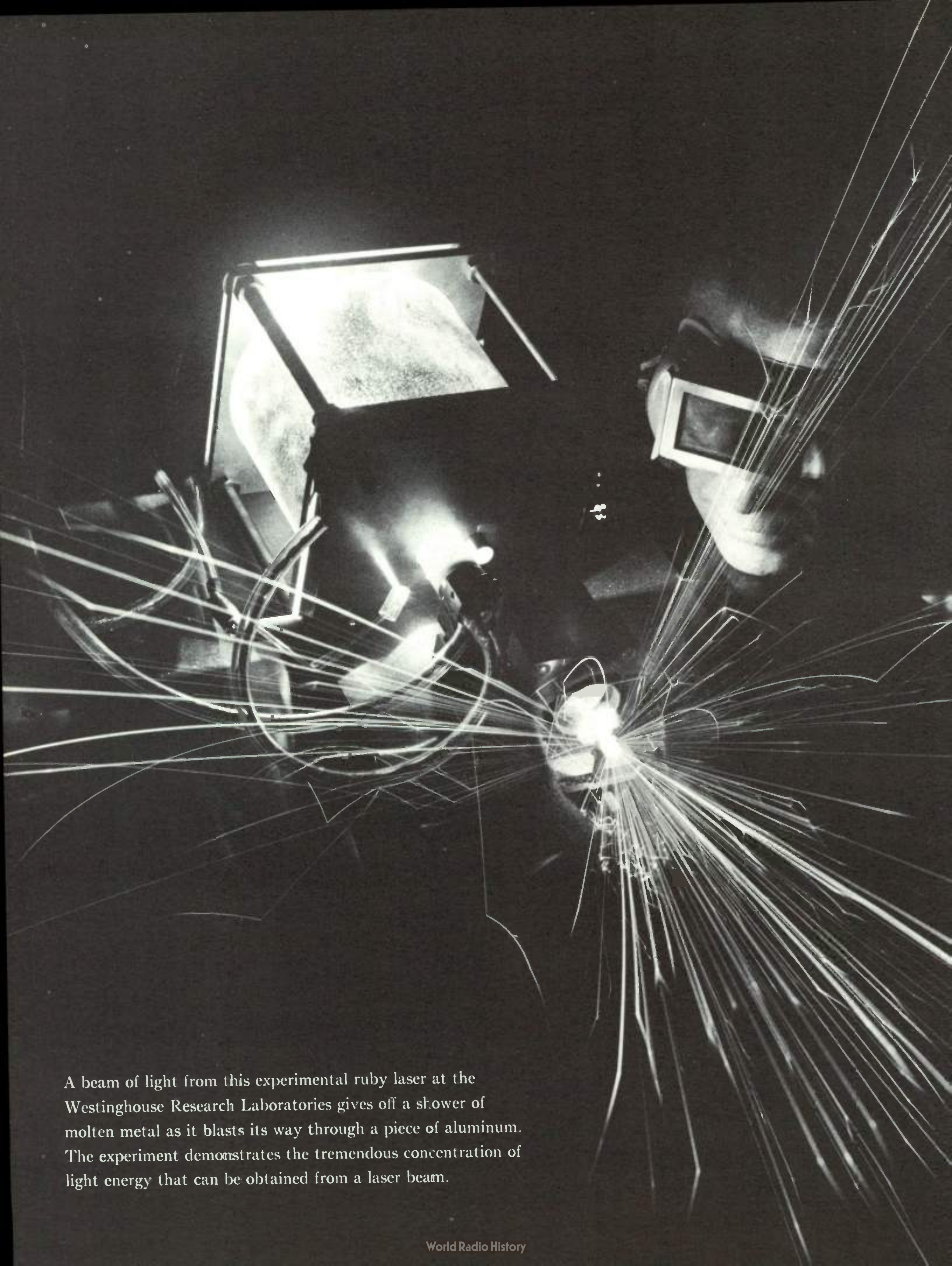
Paul Cohen and *Harvey W. Graves* are a natural team for this month's article on chemical shim control for nuclear reactors. Cohen's field is the chemical aspects of nuclear power plants; Graves' is the physics design of nuclear power reactors.

Cohen received his BS degree in physical chemistry from City College of New York in 1934 and later earned his master's degree from Carnegie Institute of Technology in 1941. Prior to joining Westinghouse, he spent 13 years in combustion research at the U. S. Bureau of Mines. Since joining Westinghouse in 1949, he has dealt with most research and development aspects of reactor coolants, as well as with irradiation of fuel elements. Cohen is now manager of the Chemical Development Department of the Atomic Power Department; he is responsible for the chemistry section, technical service laboratories, and test engineering.

Graves earned his BA degree in Engineering Science from Dartmouth in 1950, and his master's degree in Electrical Engineering from Thayer School of Engineering in 1951. He completed the Westinghouse design school in 1952, and in 1953 graduated from the Oak Ridge School of Reactor Technology. During most of his subsequent career he has been concerned with nuclear design and reactor physics for commercial reactors. Since 1956, he has been manager of Nuclear Engineering at the Atomic Power Division.

Heinz G. Sell, author of the article on ultrapure metals, is a supervisor of metals research at the Lamp Division, where his prime field is the physical metallurgy of tungsten and other refractory metals and alloys.

Sell is a graduate of the University of Munich, where he earned his BS in Physics in 1949, and his Master's degree in 1951. He joined the Westinghouse Lamp Division in 1954, where he first became associated with the equipment design section; here he helped develop automatic electronic test equipment and servo systems. In 1956 he transferred to the lamp research department in metals research, where he has engaged in investigations of sintering, optical properties of solids, electronic structure of metals, and the incandescent emission characteristics of metals and nonmetals. Since 1958, he has also done intensive work in the field of producing ultrapure metals and alloys.



A beam of light from this experimental ruby laser at the Westinghouse Research Laboratories gives off a shower of molten metal as it blasts its way through a piece of aluminum. The experiment demonstrates the tremendous concentration of light energy that can be obtained from a laser beam.