Westinghouse ENGINEER

July 1971

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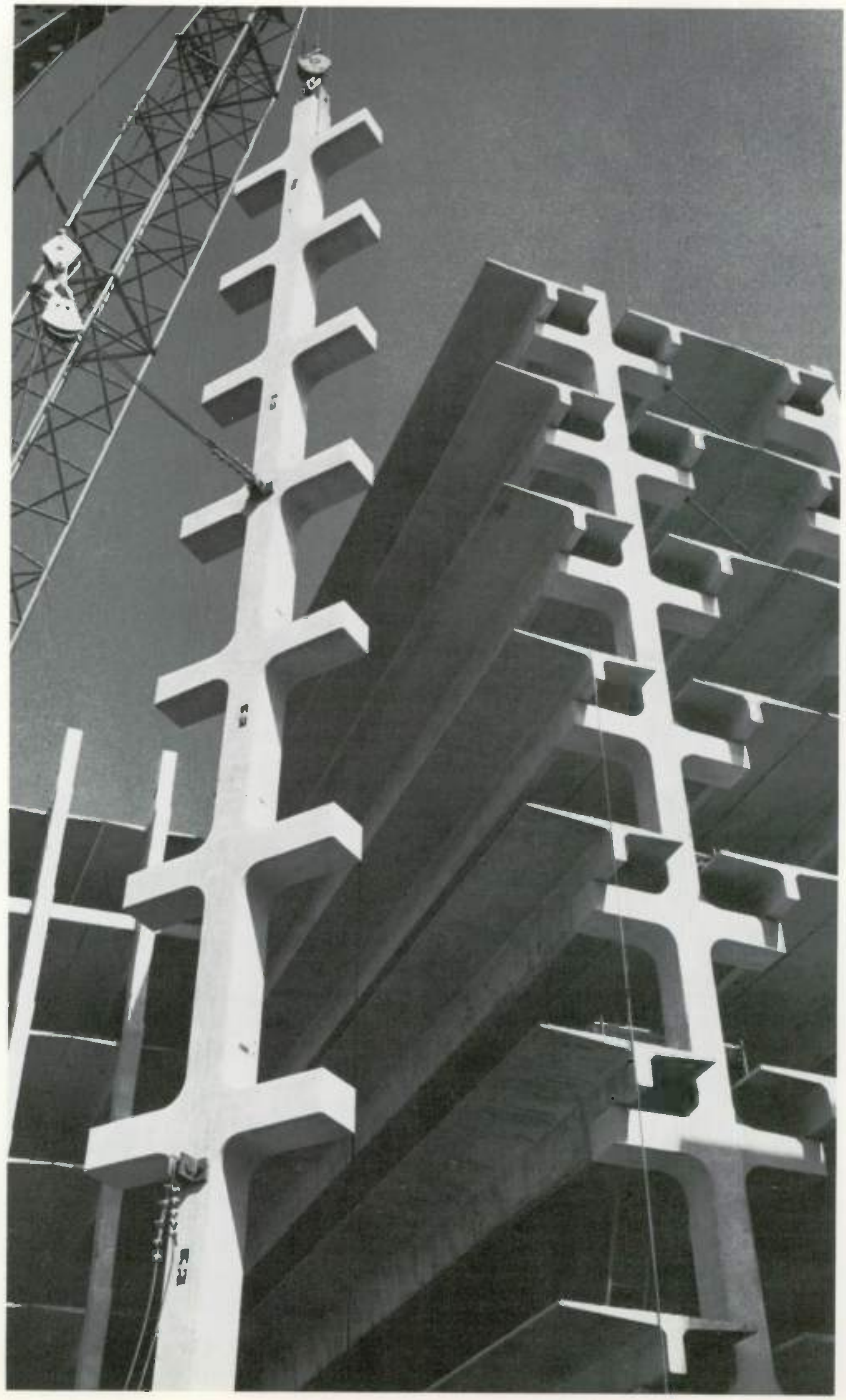
Parking Garage Assembled from Precast Concrete

Precast prestressed concrete members make up most of the structure of a parking garage built recently in New Haven, Connecticut, for the New Haven Parking Authority. Sixteen columns, each 80 feet tall and weighing 40 tons, support 437 "tee" shapes that form the floors of the 70-story 750-car Crown Street Parking Garage.

All of the precast prestressed members, which also included girders and walls, were supplied by C. W. Blakeslee & Sons, a Westinghouse subsidiary located in New Haven. Blakeslee's subsidiary, the Dwight Building Company, was the general contractor.



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Front Cover: Two key components developed for a coal mine rescue and survival system—a movable survival habitat and an extra-low-frequency communications receiver—are illustrated in this month's cover design by Tom Ruddy. These devices and others that make up the total rescue and survival system are described in the article that begins on the following page.

Back Cover: A simulated core mock-up for the Fast Flux Test Facility is used to test the core restraint mechanism and fuel-handling components. The Facility, located at the Hanford Engineering Development Laboratory, is the U.S. Atomic Energy Commission's number one priority in its Liquid Metal Fast Breeder Reactor Program. The Laboratory is operated by WADCO Corporation (a subsidiary of Westinghouse), which expects fast breeders to be widely used for power generation in the 1980's.

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A Coal Mine Rescue and Survival System

R. P. Taber
R. C. Banta

Coal mining probably has the highest safety standards of all underground workings because of the inherent hazards involved: most coal seams release explosive methane gas, coal dust suspended in air is explosive, coal burns, and coal occurs in fairly weak sedimentary formations in which roof falls are common. Moreover, since more tons of coal are produced than any other mineral, more men are employed, creating a greater exposure to accidents in coal mines than that in other underground work.

A major effort to reduce the hazards of coal mining was set in motion by the Coal Mine Health and Safety Act of 1969, passed by Congress in the wake of the disaster at Farmington, West Virginia. Under the sponsorship of the U.S. Department of the Interior's Bureau of Mines, the National Academy of Engineering conducted an extensive study of problems involved in protection of coal miners and surveyed the nation's storehouse of technology for possible solutions. The Academy made numerous recommendations for improving working practices and safety procedures to maintain the health of miners under normal conditions and for preventing explosions, fires, and other major disasters. These recommendations are being put into practice.

Recognizing, however, that disasters occur in spite of the best safety efforts, the Academy also devoted a substantial portion of its recommendations to the definition of a mine rescue and survival system that could be developed as quickly as possible, taking advantage of existing technology.[1]

The coal mine rescue and survival system guidelines issued by the Bureau of Mines have three basic objectives: to enable miners who have survived a disastrous explosion or fire to survive the equal dangers that immediately follow, including carbon monoxide poisoning, smoke inhalation or suffocation, roof falls, or additional explosions and fires; to enable miners to receive and send emergency communications regarding their locations, available escape routes, nearby dangers, or advice on rescue; and to provide a means for emergency escape if operating shafts or tunnels have been blocked and cannot be safely reopened.

The implementing of those objectives offered exceptional opportunities to apply some of the recent technology developed for various underseas and space applications. For example, the survival habitat and underground breathing apparatus concepts, although dealing with different problems and a different environment, are closely related to technologies used in underwater life-support systems. Those systems, built by the Westinghouse Ocean and Engineering Center, have been adapted to permit man to perform proficiently in the contaminated air that can exist in a coal mine when the normal environment is disrupted.

Similarly, extensive experience in seismic communications systems had been accumulated by the Westinghouse Georesearch Laboratory in its work in communication through the earth and in field tests of such systems in mines. This experience, coupled with work by the Westinghouse Defense and Space Center, made it possible to match and in some cases exceed the capabilities called for in the National Academy of Engineering report. Drilling equipment and design were provided by a subcontract team.

In addition to developing the systems hardware required to accomplish the above objectives, the Westinghouse effort also included research on the geological characteristics of major coal mining areas, accessibility of the areas from nearby airports, coal mine explosions and disasters, and even some limited studies of the behavioral patterns of trapped miners.

The Emergency Situation

Coal mines differ from each other because of differing geology, geography, mining methods, size, depth of coal seams, strata characteristics, and competitive aspects. However, the quantity of coal produced can be used to give some measure of the extent of a mine. A large mine produces in excess of 500,000 tons per year, with some very large ones producing more than 3,000,000 tons per year. A medium size mine may produce between 100,000 and 500,000 tons per year, and it may have several crews of 8 to 15 men working at coal faces within an area of one or two square miles. Similar crews may be working at faces a few miles distant, and many miles of underground tunnels are common. In addition to the crews at or near working faces, smaller teams of two to four men may be engaged in such tasks as coal hauling, maintenance, construction, or inspection at various locations underground.

If an explosion or fire occurs at one of the working faces, those who survive locally or at other workplaces must escape to the surface or find their way to designated areas equipped for construction of barricades to keep out suffocating gas while they await rescue. Since all coal mines are now required by law to maintain up-to-date maps of their tunnels, rescue forces on the surface should have information on the location of all working faces and preferred barricade areas. However, power probably will have been disrupted or, if not, disconnected as a safety precaution against sparks from broken lines. It is also probable that conventional telephone communications systems between surface and mine have been broken and may not be available for trapped miners to tell rescuers which survival areas they occupy.

Smaller groups of men moving from one area to another might be trapped in

[1]*Mine Rescue and Survival* (Final Report), National Academy of Engineering, March 1970.

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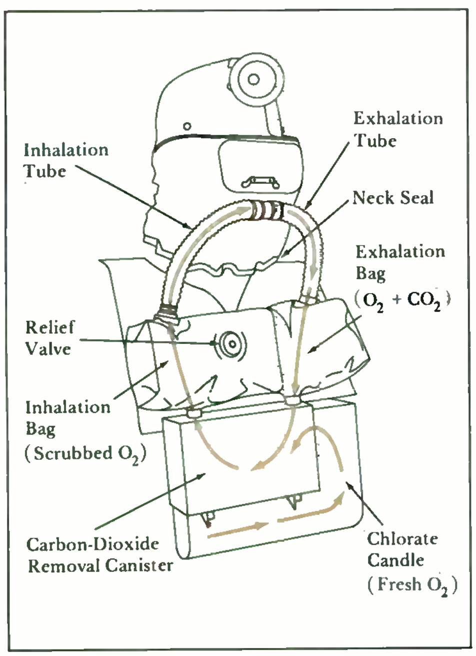

1—Breathing apparatus for miners trapped in a mine with unbreathable atmosphere employs ideas developed in underwater apparatus. It generates oxygen and absorbs carbon dioxide.

locations without any special equipment. Their locations may be completely unknown by others in the mine or on the surface. They also may be sufficiently disoriented that they do not know their exact location.

This, briefly, is the situation faced by rescue forces today. The mine rescue system to be described is designed to cope with this emergency situation by providing means for survival, communication, and rescue.

First Comes Survival

Following a fire or explosion, the essential requirement for survival is a supply of breathable air. To meet that need, law now requires that each miner be provided with an emergency breathing device, called a self-rescuer, which will allow him to reach a safe area. The present self-rescuer uses the catalyst Hopcalite (various mixtures of the oxides of manganese, copper, cobalt, and silver) to remove carbon monoxide from inhaled air by converting it to carbon dioxide; however, oxygen must be supplied by the atmosphere remaining in the mine.

Although these self-rescuer units have saved many lives, they are only marginally adequate. A major disadvantage is that carbon monoxide conversion is an exothermic reaction; for concentrations of carbon monoxide higher than about 1½ percent, the temperature of the inhaled air becomes almost intolerable.

Another disadvantage is that the percentage of carbon dioxide in the air breathed by the wearer of the self-rescuer is increased by three factors: first, a mine fire or explosion substantially increases the concentration of carbon dioxide in the atmosphere; second, carbon monoxide conversion by the self-rescuer produces an equal amount of carbon dioxide; and finally, some of the wearer's exhaled breath, which contains carbon dioxide, is rebreathed. Carbon dioxide is a powerful respiratory stimulant, causing an involuntary increase in the volume of air inhaled each minute even though there is no change in work rate. Thus, although a few percent of carbon dioxide is not in itself harmful, the effect of the gas is to increase the breathing rate of the wearer, possibly causing fatigue and reducing the life-time of the self-rescuer.

A more suitable emergency life support device should provide a respirable atmosphere regardless of the environment. It should provide this atmosphere for the longest possible duration, and the apparatus should be light and compact enough that miners will not object to carrying it continuously. And finally, the device should permit voice communication so that the miners can pass through heavy smoke and dust, which may not permit them to see, and still communicate by voice.

Personal Breathing Apparatus—A new personal breathing apparatus was designed to satisfy the above requirements. It uses many ideas similar to those used in self-contained underwater breathing apparatus (scuba) and proven deep-diving technology, not only providing a supply of oxygen but also absorbing exhaled carbon dioxide so its user can rebreathe unused oxygen (Fig. 1).

The closed-circuit system uses lithium hydroxide to remove carbon dioxide and a chlorate candle to provide oxygen by chemical reaction. Other carbon dioxide absorbants such as baralyme and sodasorb were considered; however, a tradeoff study showed lithium hydroxide the best absorption material primarily because of the smaller developmental risk in using it.

Chlorate candles, which are made of alkali-metal chlorates, were selected because they have been much improved in the past decade and are widely used as emergency oxygen generators. The candle designed for the personal breathing apparatus has a maximum surface temperature of 400 degrees F and gives off oxygen for about an hour. It has no wick, and the oxygen generated is carried out through a chemical bed that removes any trace gases. Exhaled air (oxygen+carbon dioxide) also passes through this lithium-hydroxide absorbant to remove any carbon dioxide before recirculation. Excess oxygen passes out a relief valve.

The apparatus consists basically of a plastic hood, eyepiece, rubber neck seal, canister worn across the chest, breathing bags, connecting hoses, and mouthpiece.

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Its user can talk by removing the mouthpiece momentarily and can hear through the hood. The size of the unit when stowed in its carrying case is 10 by 11 by 4 inches, and it weighs 8.28 pounds. It can be attached to the miner's belt or stored at readily accessible places.

Survival Shelter—When unable to escape from the mine after an explosion or fire, miners are trained to isolate themselves from harmful gas by erecting barricades of wood, brattice cloth (heavy cloth used for making temporary partitions and controlling ventilation currents), and other materials. Although barricades save many miners, many fatalities have also occurred because of lack of sufficient air behind the barricade, because the air was contaminated before the barricade could be constructed, because the air gradually became contaminated by exhalations from the trapped men and by small leaks, or because the air could not be circulated to eliminate impurity concentrations.

Since there is much life-saving potential in a better refuge area, the National Academy of Engineering recommended development of advanced shelters. Two types—portable and permanent—were designed as subsystems of the Coal Mine Rescue and Survival System.

The portable shelter accommodates 15 people for two weeks at the minimal level of comfort required to survive in isolation from an unbreathable mine atmosphere. It is made of six modules with bulkheads installed at each end and bolted to the floor (Fig. 2). It is a quonset-type structure 48 feet long, 9 feet wide, and 5½ feet tall at its center.

The shelter is intended to be disassembled, moved, and reerected periodically as mining advances. To meet this portability requirement, the shelter can be folded into six modular packages, each with rubber-tire wheels that are removed when the module is in place (Fig. 3). Each module weighs about 4100 pounds and can be moved by small electrically powered vehicles or by several men.

The portable refuge chamber is designed to provide some protection from both single and multiple explosions. Its arched walls are made of steel and are ribbed for strength. The end bulkheads are made of flat corrugated sheet steel and are reinforced with beams; they and the end platforms are so designed that pressure loads on them are borne mainly by anchor bolts in the mine floor. The entire surface of the chamber can withstand a hydrostatic pressure of +20 psi to −5 psi and a uniform dynamic pressure of the same amount on either end. These pressures are typical of the blasts experienced in mine explosions.

Oxygen for the refuge chamber is also provided by chlorate candles. These candles are approximately 12 inches long and 5 inches in diameter, and when burned they liberate about 72 cubic feet of oxygen. (Human oxygen consumption is about 25 cubic feet per man-day.) The candle holder has a heat sink to prevent candle wall temperatures from creating a safety hazard.

The chlorate candles are part of a self-contained system referred to as an atmosphere conditioning unit (ACU). Two ACUs are provided in the chamber. Each contains an oxygen generator (chlorate candle), carbon monoxide removal canister, carbon dioxide removal canister, manually operated blower, and built-in breathing manifold (Fig. 4). The two would normally be used alternately.

Chamber air is drawn through the ACU by a hand-operated blower, scrubbed of carbon monoxide and carbon dioxide, supplied with oxygen, and circulated to the breathing manifold, which can supply individual breathing masks or provide air directly to the chamber. The masks probably would be donned initially and the blower used to rid the chamber of smoke or other impurities, and then air would be supplied to the chamber. ACU operating frequency would depend on the atmosphere in the chamber. Simple measuring devices are provided to show the critical gas concentrations. If oxygen content is at least 18 percent, carbon monoxide concentration not greater than 0.01 percent, and carbon dioxide concentration less than 0.5 percent, the ACU is not used. When needed, the blower would normally be operated for 15-minute intervals.

Besides the oxygen-generating and carbon-dioxide-removal systems, the life-support equipment includes food, water, a 12-volt zinc-air battery, bunks, medical supplies, methane detectors, carbon monoxide detectors, oxygen level detectors, and six personal breathing apparatus to permit those in the refuge chamber to leave it to aid others or to check conditions outside the chamber.

In addition to the portable shelter, designs and specifications have been prepared for a centrally located permanent chamber that can accommodate 50 men for two weeks. It is a 75-foot arched steel tunnel located in the mine, with a reinforced-concrete blast wall at each end (Fig. 5). A pipeline to the surface provides a channel for fresh air, communication, and additional supplies. The pipeline links the survival chamber with a small building on the surface that houses a compressor and equipment to condition the air for both winter and summer. As a precaution, the permanent shelter is also outfitted with equipment to make it self-sufficient for five days—time enough to make the pipeline usable again if it is damaged.

The large permanent shelter can provide much more comfort and greater convenience than the portable shelter—more comfortable bunks, better lighting, and temperature control. It would be placed at a convenient central underground location, with accommodations determined by the requirements of the mine.

Communicate and Locate

Once the coal miner has survived the dangers immediately following an explosion and has found refuge, his next step is to make his whereabouts known to surface rescue teams. Meeting that need is the purpose of the emergency communications system.

The system has two parts: an electromagnetic system that provides through-the-earth radio transmission of voice or beacon messages, and a seismic system that enables rescuers to detect and locate vibrations produced by pounding with a pick, sledge hammer or other heavy object (Fig. 6). Use of the two systems allows the maximum chance for communications by providing redundant modes of operation and by taking into account

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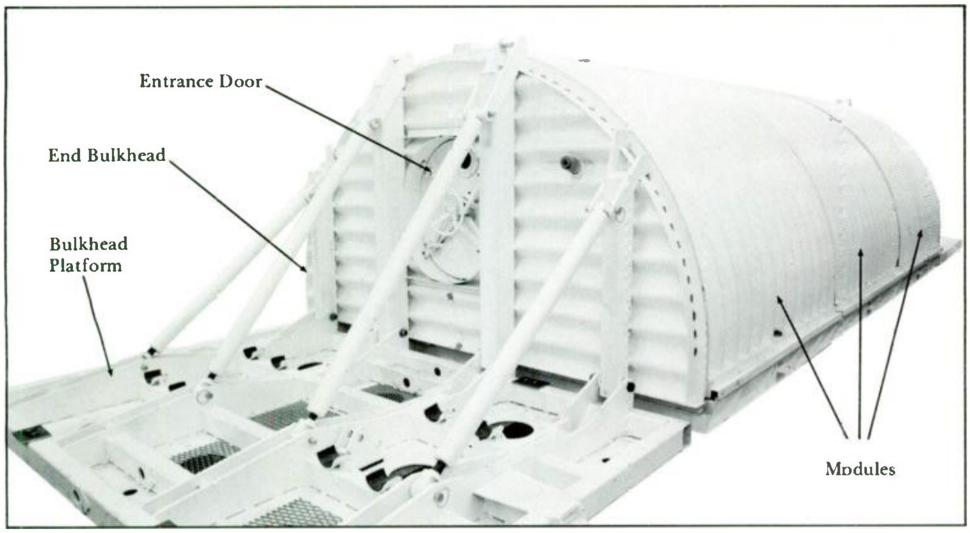

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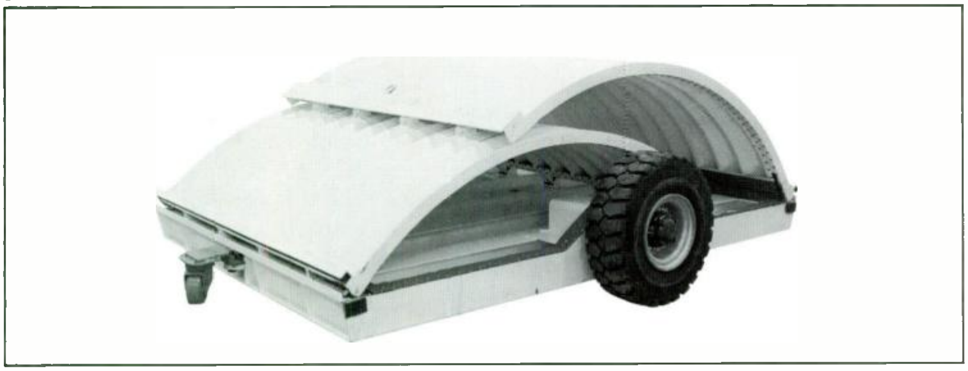

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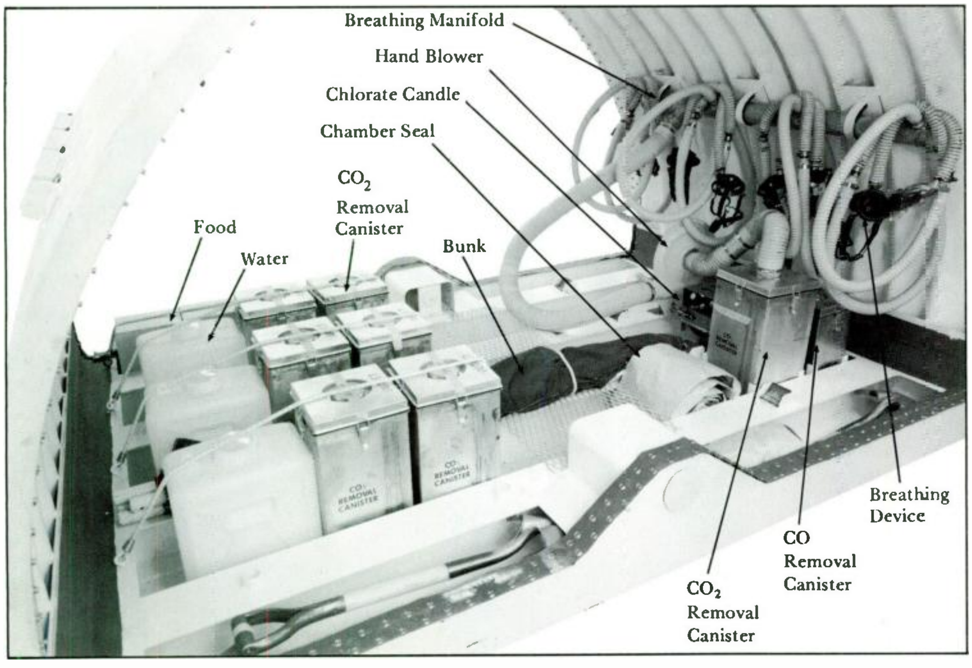

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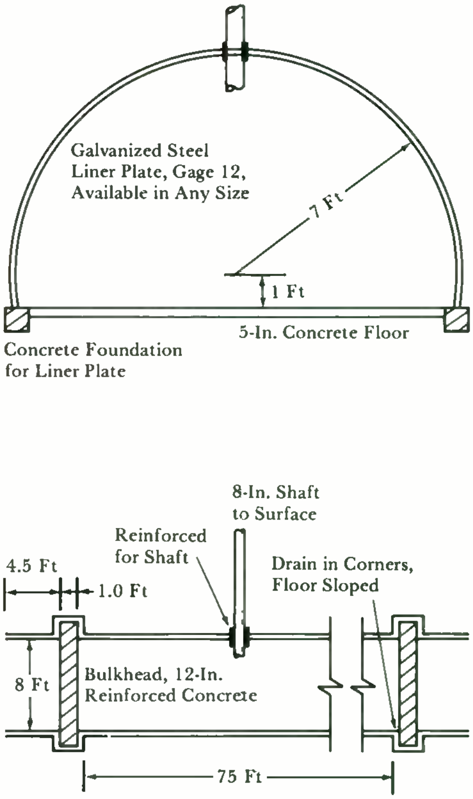

2—Portable survival shelter, designed to be kept near the working areas of a mine, provides a refuge for miners who initially survive a fire or explosion. Three of its six modules are shown, assembled with a bulkhead.

3—The portable shelter folds into six packages such as this one for periodic moving as mining advances.

4—Each portable shelter has two atmosphere conditioning units, one of which is seen at right in this photo. They are self-contained systems for producing oxygen and removing carbon dioxide. Other stored equipment is also visible.

5—Permanent survival chamber is larger and more fully equipped than the portable shelter. It would be built in a central location underground and could accommodate 50 men.

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all of the means by which a trapped miner could communicate with rescuers.

Electromagnetic Communications—The range of electromagnetic transmission for the underground system is determined by the dipole moment and conductivity characteristics. The dipole moment is defined by the equation

$$\textit{Dipole Moment} = I \times N \times A,$$

where I is loop current in amperes, N is number of turns in the loop, and A is loop area in square meters.

Surface conductivity is determined largely by the earth's "skin depth":

$$\textit{Skin Depth (meters)} = 503.3/(\sigma f)^{1/2},$$

where σ is the earth's conductivity in mhos per meter and f is the frequency in hertz. This skin depth represents the distance over which the radio signal is reduced by a factor of about $1/e$ because of the losses in the conducting medium. Bituminous coal seams are reported to have a conductivity ranging from 10^{-2} to 10^{-3} mhos per meter; the rock overlying a seam normally has a conductivity of 10^{-1} to 10^{-3} mhos per meter. Removal of coal and backfilling of mined-out areas with rock rubble probably decreases overall conductivity of those areas by a factor of two or so.

Models that depend on this skin depth are used to determine the amplitude of the total magnetic field at the earth's surface. The effects of a horizontal magnetic dipole and a vertical magnetic dipole are included in these homogeneous earth models. In practice, the field strengths calculated have proven sufficiently accurate for design. For example, during early system testing at the Imperial Coal Mine, Erie, Colorado, measured and predicted performance values were compared; the results were encouraging as they showed early in the development that the system was performing as expected (Fig. 7).

Since the effective conductivity is too high to permit operation at conventional radio frequencies, extra-low frequencies in the range of 200 to 3000 Hz must be used. The propagation characteristics at this frequency allow sufficient distance of transmission for reasonable values of radiated power. A 200-watt electromagnetic voice transmitter provides the voice communciations link from the surface to the mine. Electromagnetic transmission from a 4-watt beacon transmitter in the mine is in the form of coded signals. Six answering codes plus Morse code capability have been established. Audio transmission from the mine is not provided for.

The electromagnetic communications concept calls for each miner to be equipped with a miniature receiver (Fig. 8). This receiver can detect electromagnetic radiation and, if desired, amplify seismic signals from other miners or from the surface. The receiver is no larger than a transistor radio (1½ × 6 × 1¾ inches). It has an ear plug for listening and a geophone for receiving seismic signals through the earth.

In an emergency, the miner immediately turns the receiver on and listens for instructions. Since the tiny unit is a receiver only, an isolated miner would have to use the seismic technique (to be described) to send messages back to the surface. Instructions from the surface would inform the trapped miner to pound if he heard the transmissions; by using an established code for the responses, information could be exchanged. If signals were not heard from the miner, perhaps because he was not able to strike objects that would effectively couple to the earth, the radio would still be able to inform him that his trapped condition was known to the surface and rescue was in progress. (The miner's presence would have to be established from other information, of course, such as word from rescue teams or communications with other trapped men.)

Miners who reach a survival shelter will have a more sensitive receiver and a pushbutton beacon transmitter (Fig. 9). The beacon transmits a square-wave modulated carrier, which requires considerably less power than audio communication and so conserves its two-week battery supply.

The carrier frequency can be set from 275 to 2750 Hz, optimized for the environment. This adjustability is necessary as normal mine operations and other operations in the area can cause considerable background noise at different frequencies. Six modulation frequencies (answering codes) are provided. The codes are selected by the operator by means of buttons marked "yes," "no," "unknown," "repeat," "good," and "bad" to answer questions from the surface. The surface receiver distinguishes each signal by its modulation frequency and lights a corresponding indicator on a display panel. The codes could be used, for example, to respond to a list of names (read from the surface) by sending a "yes" or "no" after each name to identify the men at the location. In a similar manner, the extent of injuries, the quantity of supplies, and the estimated time the trapped men can remain in their location could be determined.

The transmitter is also equipped with a manual key so that a miner can answer questions by number of pulsed responses and can use Morse code if he knows it. Typical pulsed responses would establish the number of men in the shelter and how many are injured.

Seismic Communications—The requirements for the seismic system were that it be capable of rapid deployment and that it have sufficient location accuracy so that trapped miners can be reached by holes drilled from the surface or so that fairly exact directions can be given to rescue teams. The system should also be capable of maintaining a minimum level of communications.

The seismic system is based on transmission through the earth of compressional pulses (P-waves) made by striking the mine roof, floor, or walls. The signals from the mine may be from isolated individuals hammering on roof bolts, rails, metal plates, or anything else that couples the energy to the earth, or from people located at a seismic transmitter.

The seismic transmitter ("thumper") consists of doughnut-like weights that

6—Emergency communications system consists of electromagnetic and seismic equipment for communication between mine and surface and for locating men trapped underground. The exact deployment would depend on local conditions.

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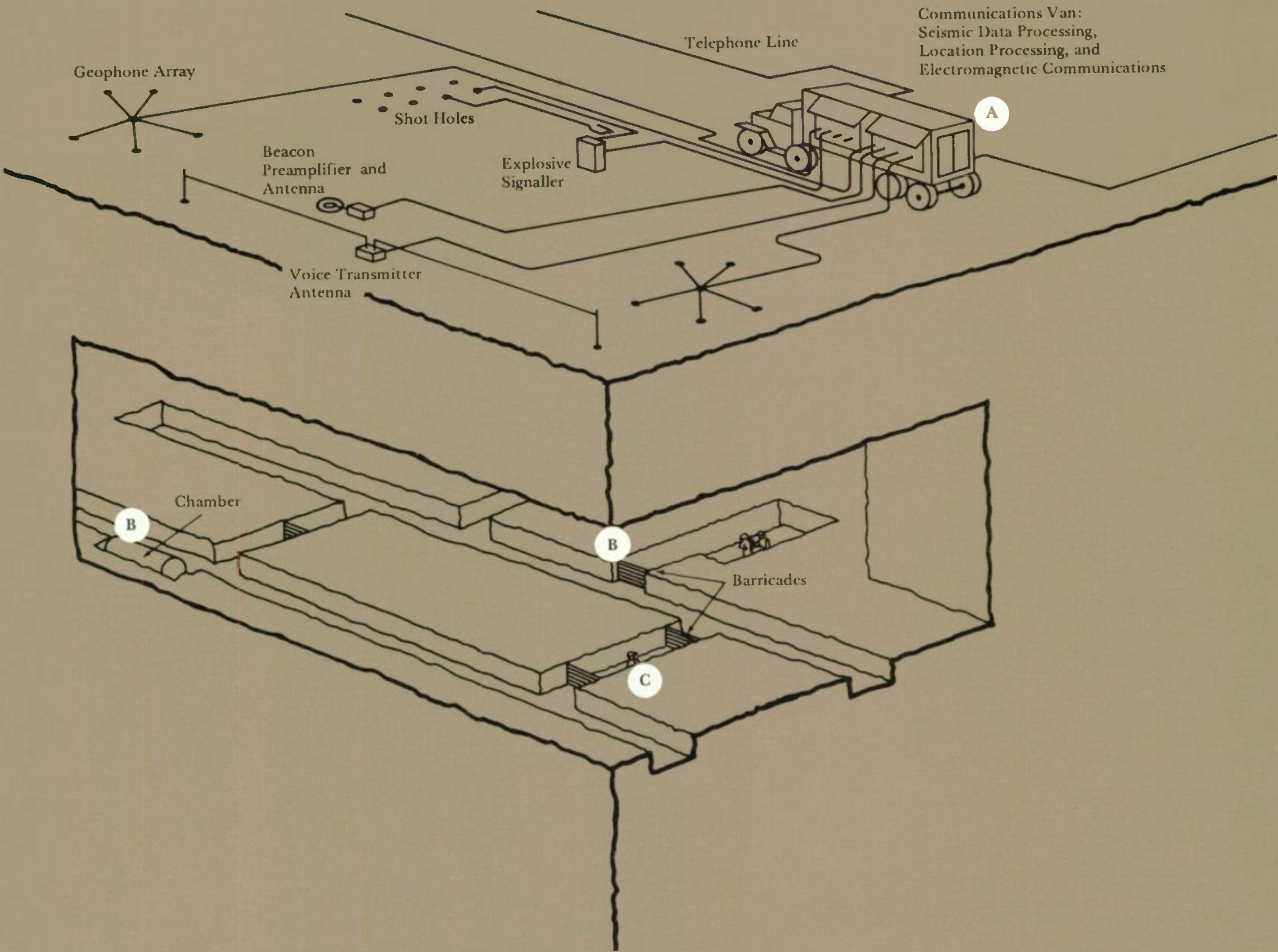
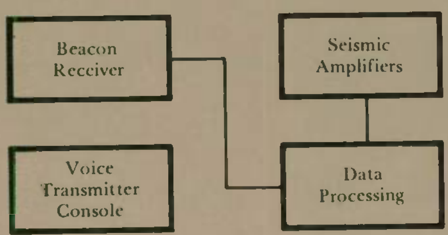
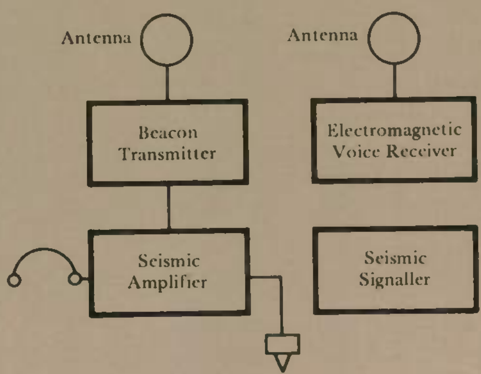


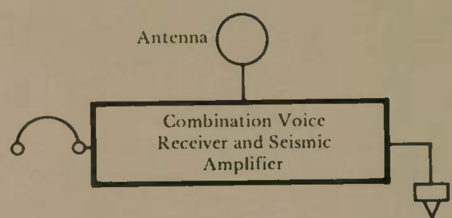
A Communications Van



B Chamber or Barricade System



C Personnel System



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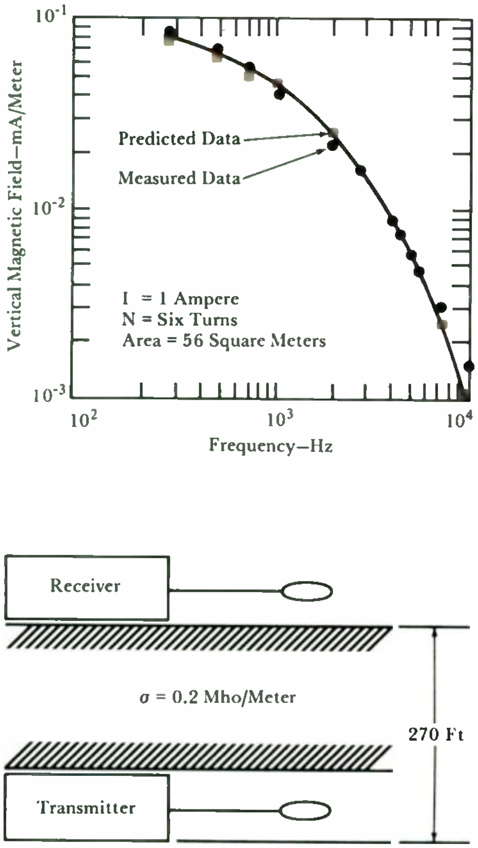

7—Measured and predicted magnetic fields for the electromagnetic communication system have compared well in field tests. The test illustrated here was made at the Imperial Coal Mine near Erie, Colorado, last July.

are lifted vertically up a center pole by compressed gas and then allowed to fall to a metal plate mounted at the pole bottom and in contact with the floor. These transmitters could be located at various places in the mines where they could be used in an emergency.

Seismic transmissions can be coded similarly to the signals from the electromagnetic system. For example, two hammer blows or "thumps" could mean "yes," and four "no." If the downlink voice transmission has been established with an isolated miner who is using seismic techniques to make his presence known, the coded-signal technique would permit information to be exchanged. Location is determined by analysis of the relative arrival times of signals at the elements of a large seismometer array.

The seismic surface system consists of at least four geophone arrays deployed over possible areas of entrapment (Fig. 10). These areas are likely to be known because of known information about the location of seismic equipment in the mine or because of information obtained from rescue teams, from men who have escaped, or from trapped men with whom communication has been established. The area covered by the geophone arrays would likely be approximately half a mile across the diagonal. Each array contains up to seven geophones.

The number of arrays used would depend on the specific situation. Seven could be used if necessary to maximize sensitivity or to overcome a geometric location problem.

Each geophone array is approximately 10 feet in diameter and is laid out in a circular pattern with approximately 5-foot spacing between instruments. The geophones are 14-Hz natural-frequency seismic instruments weighing about 1.5 pounds each. Rough azimuth setting at the array center, the use of interconnecting cables cut to the correct length, and portable wire spools for dispensing the wire permit rapid deployment.

The arrival time of the P-waves at each array provides the input for a data-processing computer, either on location or by a telephone link. The computer performs the necessary geometric computa-

8—(*Top*) Radio receiver would be carried by each miner, attached to the battery case of his cap lamp. It would pick up radioed instructions from the surface in an emergency, or, if used with the small geophone at right, could pick up seismic signals.

9—(*Bottom*) A more sensitive radio receiver and a radio beacon transmitter are located in the survival shelters. The transmitter has buttons for standardized replies to communications from the surface, and also a key for pulsed responses.

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tions to convert relative arrival times of the P-waves to position coordinates and then displays the detected locations on an XY plotter. Typical geophone array signals are shown in Fig. 11.

Computations using the area covered by the geophones, mine depth, and variations in seismic velocity in different geological layers tell the operator whether the source is inside or outside the geophone arrays. If it is inside, the method of intersecting hyperbolas is used for source location. If it is outside, an assumption of plane waves may be used and the array outputs used in pairs to find the intersection of two straight lines along the two azimuth estimates.

Once the rough location estimate is obtained, it will probably be desirable to center the arrays over the estimated location and reduce the area covered. The reduced spread should still be greater than about one third the source depth to minimize effects of irregular topography, geologic structure, and inhomogeneities. Since the source is almost surely within the smaller area, the computer program uses the intersecting hyperbola method to compute an accurate location. By including knowledge of mine depth and of P-wave velocity in the particular rock structure, it should be possible to achieve a precision of ± 30 feet—sufficient to effect a rescue under most circumstances.

The seismic system can also serve another purpose when used in conjunction with receivers and beacon transmitters located in refuge areas. After communications are established with men in a shelter, rescuers can call on them to install a geophone from their cache and connect it to their transmitter and receiver. The geophone then provides an underground sensing station to detect and relay vibrations from miners who might be trapped nearby. This capability is provided in case of difficulty in detecting P-waves from large depths, or through difficult geologic formations. Of course, this requires that the position of the shelter and deployed underground geophone be accurately known in advance by underground surveying and measurements.

Drills for Rescue

Coal miners who survive a disaster most often come out the way they went in—through the mine entrance. However, there have been times when the miners have been trapped and rescue teams unable to enter, so the only means of rescue was through holes drilled from the surface. If refuge chambers are provided, there will be more occasions when miners will be able to survive explosions and rescue holes will have to be drilled.

The rescue drilling system was developed by the Rowan Drilling Company of Houston, Texas. Drill bits and material removal techniques were designed to handle the geological formations of most coal fields. The system assumes rescue from rather flat bituminous coal seams less than 1500 feet below the surface; however, the drilling rigs have the capability of reaching depths of 2500 feet.

Overlying rock of relatively low to medium strength is assumed. The highest strength rock expected to be encountered is quartzite of approximately 25,000-psi compressive strength, which in a very few areas may be as thick as 60 feet.

The first contact with trapped miners is made with the highly mobile probe and search drill, which can drill an 8¾-inch hole to depths of 2500 feet. The search hole provides a means of quickly supplying fresh air, food, medical supplies, and wire communications. The drill can bore reasonably straight holes, although the hole tends to spiral as it is drilled. (If averaged over a sufficiently large depth, the hole would not deviate more than 2 degrees in 500 feet.) Penetration speed is as high as drilling conditions permit, with a goal of 100 feet per hour in 12,000-psi rock and 20 feet per hour in 25,000-psi rock. Weather, crew experience, and availability of supplies (fuel, water, etc.) can also affect drilling speed.

Overlying formations should produce a relatively low volume of water (less than 100 gal/min), which can be excluded easily by casing the drill hole to seal off bad sections before proceeding to the total depth. Excessive formation water must always be sealed off before drilling into the mine.

Rescue drilling system includes this probe drill, shown working at a mine site near Gary, West Virginia. It quickly bores a hole 8¾ inches in diameter to locate trapped men and to provide a passage for air and supplies. A larger drill then bores a 28½-inch hole, if necessary, for removing the men from the mine.

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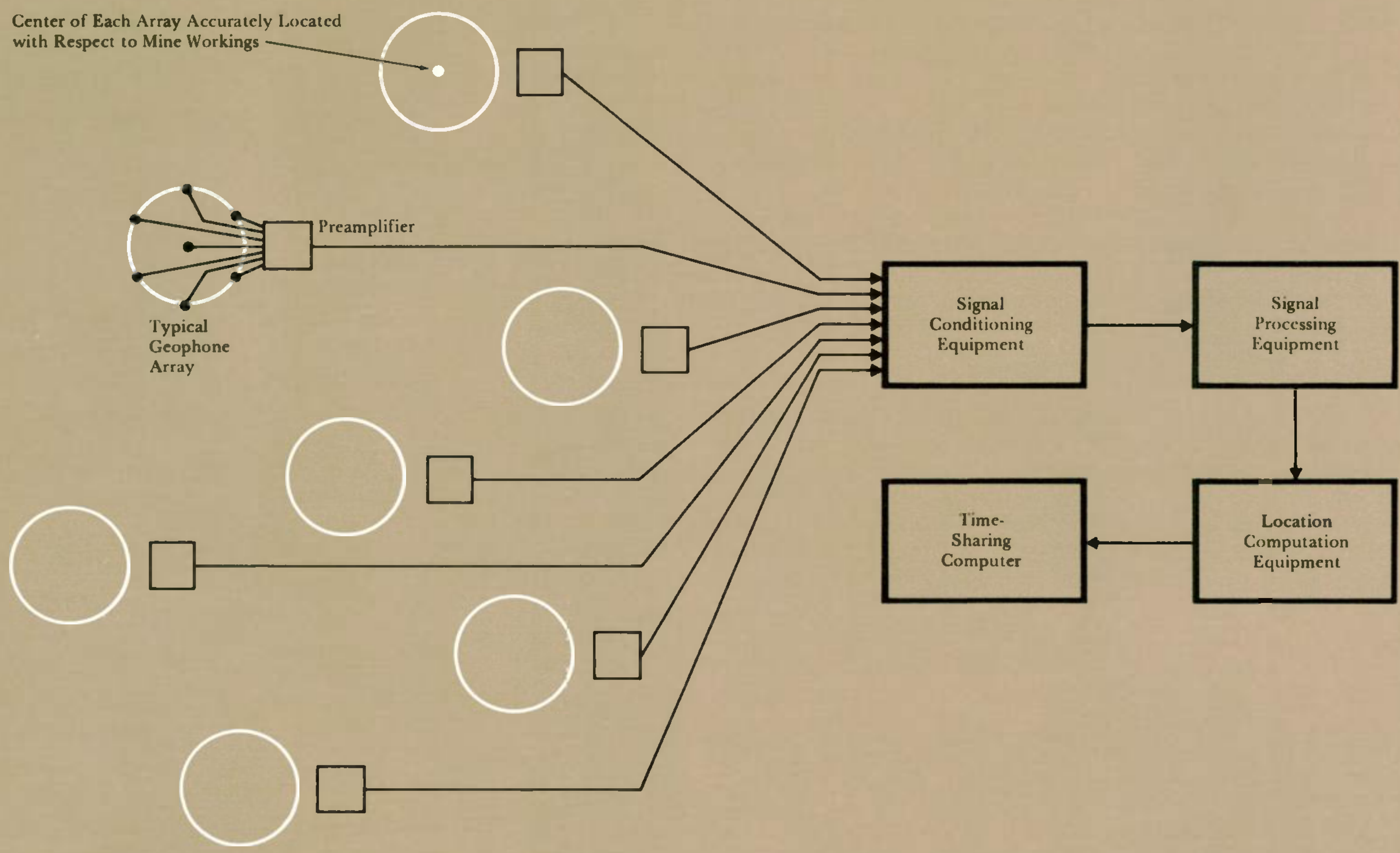

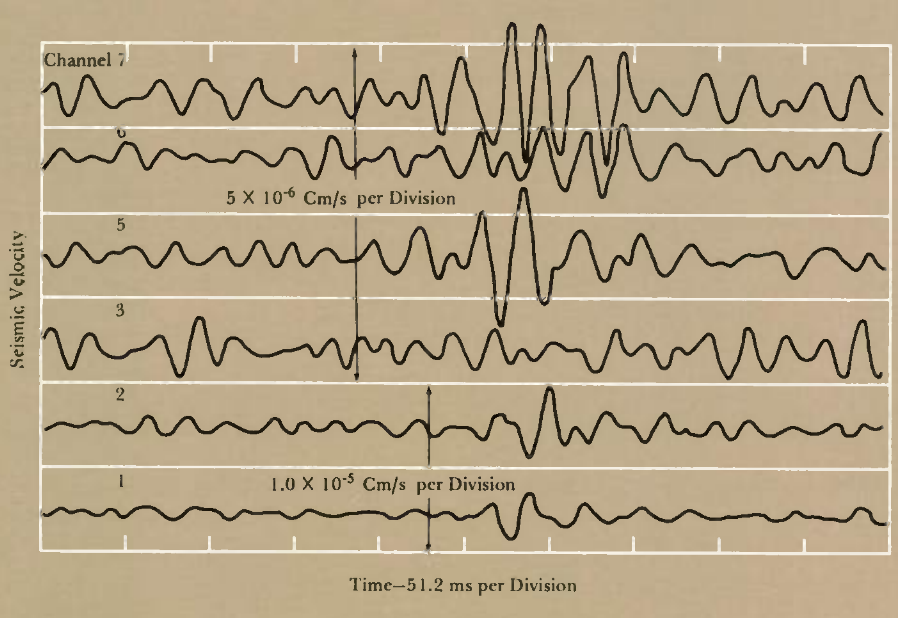

10—(*Top*) Seismic communications system includes geophone arrays, placed on the earth's surface, that pick up seismic signals from men below. From four to seven arrays would be used. Each array would be about 10 feet in diameter, and they would cover an area about half a mile across.

11—(*Right*) Typical signals from a geophone array were recorded during a test and demonstration of the communications and rescue systems at the Gary site early this year. Processing the data established the source of the sound waves accurately enough to have allowed rescue of the man, who was pounding on the mine floor with a 10-pound sledge.

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A rotary drilling procedure was selected for the probe drill and rescue drill. It is accomplished by rotating a drill bit attached to a drill pipe that extends back to the surface. Weights are added to the bit to cause cutting. Weights are necessary because the drill pipe is operated in tension mode rather than compression, as its relatively thin walls do not favor operating in the compression mode. Cuttings are cleaned from the bit and removed from the hole by a water-base drilling fluid or by air circulating across the drill bit and back to the surface.

A variety of air circulation procedures can be used, depending on the situation encountered. A common technique, and one useful for breaking into areas where men are trapped, is the reverse air-vacuum circulation method. A vacuum is applied to the inside of the drill pipe at the rig level to create a pressure difference between the pipe and the hole bottom. The resulting air flow passes across the bit, picks up the cuttings, and transports them to the surface through the pipe. The technique permits rotary drilling with a bottom-hole pressure substantially at atmospheric pressure, which is very important for drilling safely into areas where personnel are trapped.

The most common mining method in the United States today is the room and pillar technique. In a mine employing it, the probe drill would be aimed at an open area in the mine between coal pillars. This area may be 20 to 80 feet wide. If it were missed, it probably would not be by more than a few feet. The miss would be known immediately on the surface because the depth to the coal would be known. If the drillstring does not fall into the open area or if coal comes out with the air circulation, obviously the drill has deviated into a coal pillar. If there are miners in the open area, they will hear the drill. The depth into the pillar (distance from the open area) will be so slight that unless the miners are injured they can dig their way to the drill hole. Thus, even if the open area were missed, rescue would be possible.

Following initial contact with the search hole, rescue drilling can proceed at a slower pace to provide a separate 28½-inch-diameter escape hole. While the rescue hole is being drilled, the discovery hole will probably have to be resealed except for a few hours each day to protect the men from dust created by the rescue drill.

If the men are in a rather confined area, the last 10 feet of rescue hole drilling must be done very slowly, particularly if the coal is overlain by a weak formation. This slower drilling rate, where required, would be at about 2 feet per hour.

The rescue drill is also capable of drilling to a depth of 2500 feet. It drills with air circulation for removing cuttings, and, like the probe drill, it can set casing to prevent water or other contaminants from interfering with the drill and rescue operation. Also like the probe drill, the rescue drill will drill as fast as conditions permit; it has as a goal speeds of 17 feet per hour in 12,000-psi rock and 6 feet per hour in 25,000-psi rock. It has a half-inch wire-rope personnel hoist. The rope is an anti-spin type and has a rated breaking strength of 19,700 pounds; its length is more than adequate for depths of 2500 feet.

A capsule has been designed for pulling miners out through the 28-inch hole. It is pointed at each end to prevent catching on rock shelves or "doglegs" in the hole. The capsule is capable of completely enclosing an injured man strapped to a stretcher. Both the top and bottom of the capsule are jettisonable so that the passenger can be raised or lowered independently if the capsule should get caught.

The primary differences between the coal-mine rescue drilling rigs and similar rigs in use by the petroleum industry are portability and versatility. The drill rigs selected for this application are capable of being transported on conventional highways, moved across the very rugged terrain likely to be found near mining areas, or broken into packages capable of being airlifted. For most mine locations, the search drill could be on site and drilling within hours. No more than three or four holes should be required to make contact with trapped miners. Thus, in most cases, miners would be contacted within 25 hours.

The heavier rescue rig would have been dispatched to the drilling site and should be ready to start drilling by the time the search drill has located the men, or perhaps used simultaneously to drill additional 8¾-inch holes in search of survivors.

Applications

The Coal Mine Rescue and Survival System has been exercised twice in rescue operations. The first use was in January and February 1971 when an emergency situation was simulated at U.S. Steel's No. 14 Mine near Gary, West Virginia. Tests of the communications and location equipment, the drilling equipment, and the rescue procedures were successfully carried out. The tests were conducted under simulated emergency conditions even to the extent that, prior to official notification, Westinghouse personnel who were to participate in the testing did not know precisely where or when the test and demonstration was to occur. Additional tests of the survival shelter were conducted during February 1971 at the Bureau of Mines Experimental Mine at Bruceton, Pennsylvania. There the shelter was tested for its life-support ability by having people live in it for a period of time, and it also was subjected to controlled explosions.

The second use of the equipment began in late March 1971 at Nemacolin Mine, Nemacolin, Pennsylvania. The drilling and the communications and location equipment were used in a situation where a mine fire had occurred and two men were known to be trapped in the mine.

The system is an improvement over present mine rescue and location tools. It gives additional means of effecting rescue to augment "through-the-mine" techniques already in use.

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Reverse Osmosis: A New Tool for Water Purification

J. B. Wright

Reverse osmosis now provides an economical means of purifying contaminated water, and it also can help attack pollution problems with its ability to concentrate industrial process fluids and municipal wastes for recycling or efficient disposal. The Westinghouse reverse osmosis system employs several unique material and fabrication features that combine high strength and performance with long life and flexibility.

The problem of meeting the water requirements of the world, and doing so economically, becomes ever more complex as population growth increases the demand for potable, industrial, and agricultural water. Furthermore, sophisticated manufacturing processes are requiring higher qualities of water than ever before. However, many local water sources are unsuitable for direct use, and the municipal and industrial contaminants that are discharged into the waterways are making purification by conventional methods increasingly difficult. To help solve these purification problems, new tools such as reverse osmosis have been developed.

Reverse osmosis is well suited for treatment of brackish water to provide drinkable water for municipal systems since, in addition to removing dissolved and suspended particles, it also removes bacteria and viruses. Other potential uses include purification of boiler feedwater, reclamation of treated municipal waste water, and water softening for beverage manufacture.

In some processes the by-product of reverse osmosis is just as useful as the purified fluid. Treatment of mine drainage, for example, not only would yield purified water, but the by-product solution may contain attractive amounts of useful minerals. Other examples include reclamation of protein and lactose from cheese whey, and concentration of industrial fluids such as detergents and dyes for efficient disposal or reuse.

J. B. Wright is Project Manager, Reverse Osmosis Systems, Westinghouse Heat Transfer Division, Lester, Pennsylvania.

Osmosis Principles

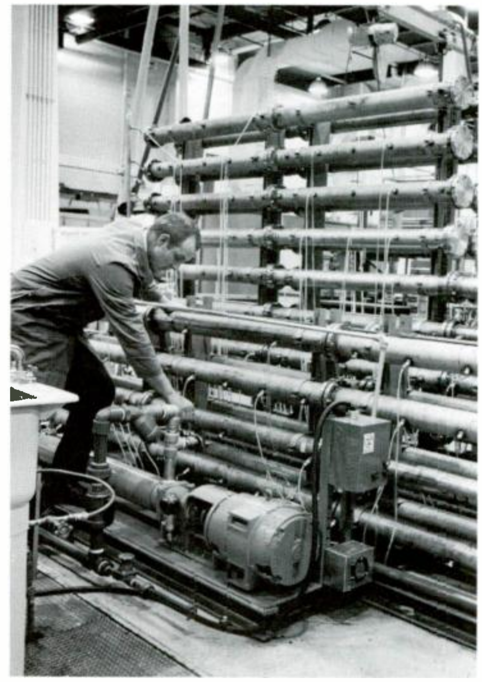
Osmosis is the natural process by which plants transmit fresh water into their individual cells (Fig. 1). The walls of plant cells contain a semipermeable membrane that permits water and certain solutes (such as dissolved gases) to enter the cell but resists intromission of sugars and mineral salts. Water flows into a limp cell because the diffusion pressure (pressure due to the random motion of molecules) of the cell sap is less than that of the water surrounding the cell by an amount called the sap's osmotic pressure. As water enters, the cell expands until the sap's diffusion pressure balances the effect of its osmotic pressure. When the osmotic equilibrium pressure is reached, the sap's diffusion pressure equals that of the water surrounding the cell, so the number of water molecules entering the cell equals the number leaving. This process can be reversed by exerting a greater pressure on the sap side than the osmotic equilibrium pressure, causing fresh water to be forced out of the sap solution and through the membrane. That is reverse osmosis.

Reverse osmosis can separate water (and some other liquids) from various contaminants such as dissolved salts, colloidal suspensions, and other suspended (undissolved) solids, as well as organic materials such as bacteria, viruses, sugars, dyes, and proteins. The rejection rate is nearly 100 percent for large molecules, especially those in organic compounds.

The basic scheme of the Westinghouse reverse osmosis system for water purification is relatively simple. Brine feedwater (a mixture of dissolved and suspended salts and solids) is pressurized by a pump to several times its osmotic pressure. The feed is then piped through a modular bank of semipermeable membranes. From the membrane bank are two outputs: the product (purified) water and the blowdown (the remaining feedwater, now of higher impurity concentration). A prototype system is shown in the photograph.

Reverse Osmosis Module

A 4-inch-diameter by 4-foot-long module is the building block in Westinghouse



Photo—Reverse osmosis modules can be compactly arranged to provide pure water in any desired quantity. The 70 modules making up this 10,000-gpd prototype system are connected in a series-parallel configuration that permits optimum turbulent flow of feedwater to maintain efficient operation. A 7½-hp pump forces brine feedwater through the system while pure water is collected from two nipples in each module.

1—*(Right)* Principles of osmosis are illustrated (*a*) by an open U-tube containing equal volumes of water and plant sap separated by a semipermeable membrane similar to that in a plant cell wall. Since the diffusion pressure of the sap is lower than that of the water by an amount equal to the sap's osmotic pressure, water flows through the membrane to the sap side. As the flow continues, the sap's diffusion pressure increases until it cancels the effect of its osmotic pressure (*b*). The osmotic equilibrium pressure is proportional to the distance x, which is the difference in height of the two liquids. Since the diffusion pressures of water and sap are balanced, no net water flow occurs. In (*c*), the diffusion pressures are shown unbalanced again, but a piston is added to the sap side. Normal osmosis is prevented if the external pressure on the piston equals the osmotic equilibrium pressure. If still more force is applied to the piston (represented by an additional weight), pure water is forced out of the sap through the membrane (*d*).

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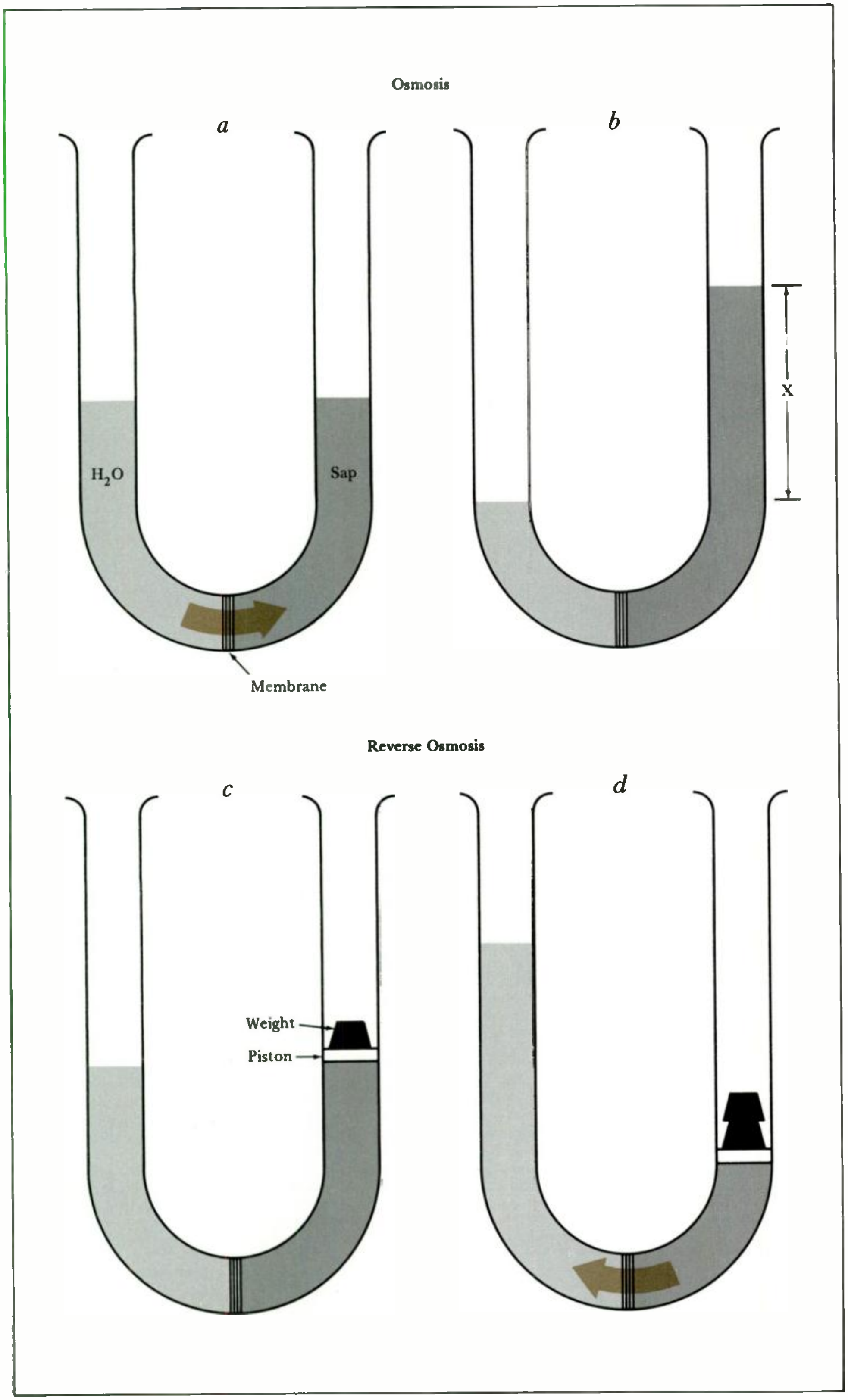

reverse osmosis systems (Fig. 2). Each module contains 18 half-inch-diameter tubular membranes supported in a porous core of resin-bonded sand. The membrane and support system is solidly enclosed in a steel tube with flanged ends for secure sealing and serial connection.

Primary design objectives for the modules included high durability and the ability to be permanently installed in an industrial environment with little or no maintenance attention. The modular design permits a wide range of system capacity, as the units can be compactly arranged to provide purified water in any desired quantity. Aside from operating flexibility, the Westinghouse modules provide several important performance features such as efficiency, reliability, and long life.

Membrane Performance and Configuration—For many years the lack of good membrane material prevented economic application of reverse osmosis. During the past decade, however, membranes have been produced from new formulations of cellulose acetate that allow a high rate of product passage (flux) while maintaining suitable impurity rejection rates. Recent improvements have also lengthened membrane life.

The flow of product water from a membrane depends partly on the effective driving pressure, which is the pressure above the osmotic pressure of the feed solution. As driving pressure is increased, flux increases almost in direct proportion. However, if a membrane is subjected to high pressures for extended periods of time it suffers physical deformation that reduces the flux. The damage is caused by compaction of the porous layer behind the osmotic skin of the membrane. Compaction for cellulose acetate membranes has a detectable threshold at some pressure above 450 to 500 psi and becomes more rapid with increases in driving pressure.

For a rejection rate of 90 percent, most other tubular cellulose acetate membrane systems must operate at 600 to 800 psi to deliver about 13 gallons of product water per square foot of membrane per day. Within a year, membrane compaction reduces the flux to about 8 gallons

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per square foot per day. The Westinghouse tubular membrane, however, loses hardly any performance due to compaction. For the same rejection rate, it can provide about 18 gallons per square foot per day of product water with little drop in performance since its driving pressure need only be 300 to 450 psi, which is below the compaction threshold. Besides lengthening the membrane life, lower driving pressure improves system economy by requiring less pumping power, less pump and valve maintenance, and no high-pressure components. The new membrane was developed by the Westinghouse Research Laboratories in conjunction with the company's Product Transition Laboratory.

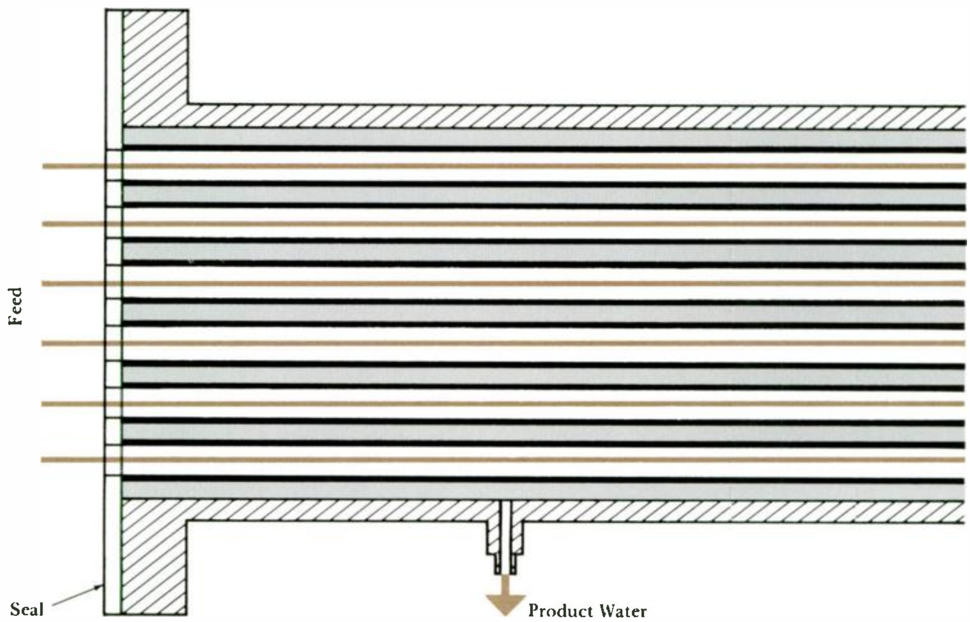
Product flux and rejection rates are determined by the driving pressure, the nature and concentration of the feedwater solutes, and the characteristics of the membrane. These characteristics can be altered in Westinghouse membranes to provide a wide range of flux and rejection rates for a variety of performance requirements. For example, if high rejection is required with solutions containing small monovalent ions such as chlorides, a "tight" membrane is used. If multivalent ions such as sulfates, or large organic molecules, are to be rejected, longer life and good performance can be achieved with a "loose" membrane. The curve in Fig. 3a represents the wide range of available rejection characteristics. Examples of loose, medium, and tight membranes are compared in Fig. 3b to show how their flux varies with feedwater impurity concentration and pressure.

The tubular membrane arrangement was chosen because, in it, feedwater follows a linear unobstructed path through the tubes (Fig. 2). Product water diffuses through the tube walls, flows through the porous support system, and is collected.

In contrast, many other systems have spiral-wound or hollow-fine-fiber membrane configurations. The spiral-wound arrangement is somewhat like a jelly roll wound with alternate layers of membrane, support material, and spacer; feedwater is forced axially along the roll, with product water emerging from the core. In the hollow-fine-fiber configuration, feedwater surrounds a bundle of self-supporting hair-thin membrane tubes. Product water diffuses into the tubes and emerges from their ends. Both arrangements present an intricate resistive path to the flow of water, which can impair performance.

While the size and weight of the Westinghouse membrane system is somewhat greater than that of alternative configurations, it is stronger and provides several operating benefits. Since a membrane allows essentially only desalted water to pass through, there is a natural tendency for brine salts to concentrate adjacent to the membrane surface. This tendency is called concentration polarization and has the same effect as increasing the osmotic pressure of the brine that the membrane sees, thus reducing the available driving pressure. Some feedwaters are nearly saturated with dissolved salts such as some of the naturally occurring carbonates and sulfates; if concentration polarization remains unchecked, the salts precipitate on the membrane and could seriously reduce product flux, thereby increasing system downtime for membrane cleaning or replacement. Concentration polarization is minimized in tubular membranes because feedwater can flow fast enough (and at the expense of reasonable pressure losses) to maintain turbulence. Thus, the feed stream is thoroughly mixed so the membrane sees only its average salinity.

To insure turbulent feedwater flow throughout a reverse osmosis system, its



2—The basic components of Westinghouse reverse-osmosis systems are 4-inch-diameter by 4-foot-long modules. Each steel-clad module contains 18 tubular membranes supported in a porous core. Contaminated feedwater at about 300 to 450 psi pressure enters one end of the module, and purified product water is forced through the membrane walls, through the sand core, and out two nipples. The fluid (blowdown) emerging from the other end of the module is the feed for the next module. A seal chemically bonded to each end of the module insures a leakproof flow path between membranes in successive modules.

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modules are connected in a particular series-parallel configuration. The arrangement is determined by the feedwater constituents and characteristics (temperature, viscosity, etc.), the membrane's flux characteristics, and the ratio of dissolved solids in the feed to that expected in the product water.

Since feedwater is able to flow relatively unobstructed through tubular membranes, such membranes can tolerate a much wider range of fluid viscosities and suspended particles than can alternative schemes. Moreover, the tubular design allows for easy membrane inspection, which only requires removal of the modules' flange connections. Membrane cleaning is also simplified; in most instances, a detergent or acid wash solution pumped through the modules provides satisfactory cleaning.

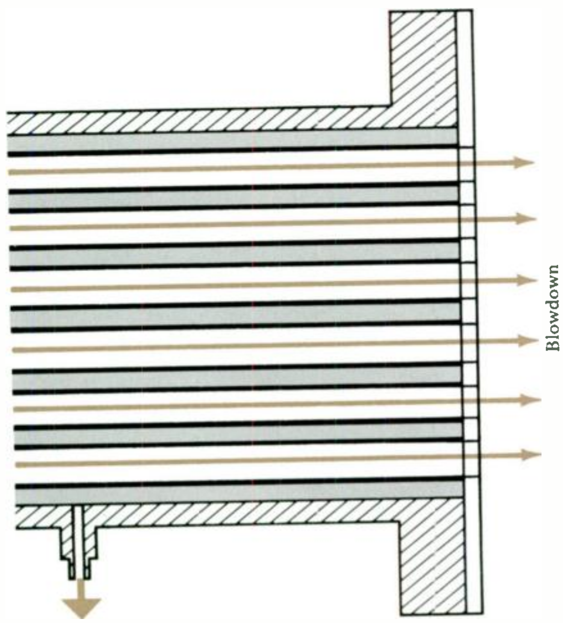
There are, however, a few feedwater conditions that can be harmful to reverse osmosis membranes and that might make other treatment methods preferable. Feed solutions above 100 degrees F, for instance, should be avoided as they can shorten the membrane life. Fluids containing abrasive materials can permanently damage the membrane and should also be avoided. If certain dissolved elements such as iron are allowed to precipitate on the membrane, they can clog the membrane until redissolved. The ideal pH of feedwater for cellulose-acetate membranes is 5.6; when a pH of about 8 is exceeded, the membrane starts to hydrolyze (chemically deteriorate), thereby losing its ability to reject dissolved solids. Often, however, the pH can be lowered to a suitable value by adding a small volume of acid to the feed solution.

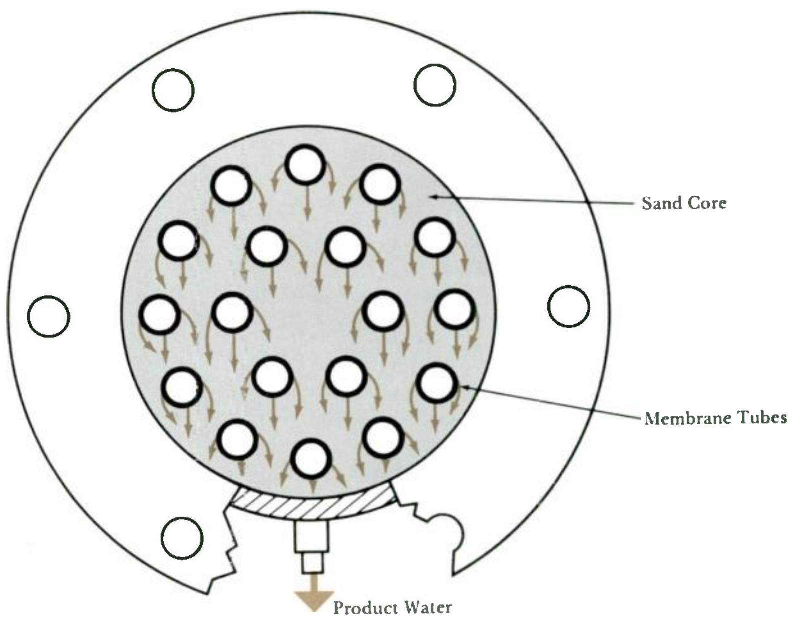
Membrane Support System—In most other tubular configurations, membranes are molded or otherwise placed into fiber-glass support tubes. However, that scheme has some inherent limitations. Since it is difficult to control the dimensional tolerances of fiber-glass tubing, the thickness of membranes that are cast on the tube walls can vary. Furthermore, creep from long-term pressure in fiber-glass can subject membranes to stresses beyond their acceptable limits and even cause bursting failure of the support tube itself. The membranes have close deformation tolerances that should be maintained for maximum life. It is also difficult to secure a high degree of permeability in fiber-glass support tubing. Good permeability is important to overall efficiency since any back pressure reduces the driving pressure just as does concentration polarization in membranes.

These difficulties are eliminated in the Westinghouse system by supporting the membrane tubes with a resin-bonded sand core (Fig. 2). The rigidity and stable long-term strength of this material make it particularly well suited for the application. Moreover, its permeability (provided by optimization studies with resins and sand grain sizes and shapes) is vastly superior to that of fiber-glass.

Support holes for the membranes are molded into the core during the resin curing process and so can be dimensionally well controlled. This insures consistent membrane wall thickness, as the membranes are drop-cast into the holes. (Membrane material is poured into the holes, followed by cylindrical slugs that force the material to the walls. The membranes are then hardened by curing.) Drop casting permits some of the membrane material to soak into the sand core walls, thereby providing a permanent secure attachment when cured. The membranes are never stretched or pinched as they could be if they were inserted or glued into place.

Module Seals — Connections between membranes in successive modules must





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be watertight to prevent feedwater from leaking into the product side. Conventionally, intermodular sealing has been achieved with mechanical seals that rely heavily upon tight connections. Such seals are subject to tolerance variations in manufacture that make them expensive as well as a potential source of leaks and membrane damage.

Westinghouse has avoided these difficulties by chemically bonding end seals to the flange, core surface, and inner edges of the membrane tubes. Permanently bonding the seals to the modules assures leakproof joints while facilitating module connection and disconnection, since no additional gasketing is required.

Field Test Program

The performance of the modular design has been verified by more than 250,000 module-hours of field testing preceded by about 170,000 module-hours of laboratory tests. Feedwater types ranged from Los Angeles tap water, which is high in carbonates, to acid mine drainage, abundant with dissolved solids such as compounds of iron, aluminum, and magnesium. Each field test unit consists of a standard 4-inch-diameter by 4-foot-long module installed in a compact cabinet with the necessary pump, gauges, and controls to permit simple connections in the field. To simplify test procedures, each field unit was also equipped with an automatic product water sampling valve, timed to open for one-minute periods to obtain flux data. Samples of the feedwater, product water, and blowdown were analyzed each week.

The first test unit was installed at the Westinghouse Heat Transfer Division, Lester, Pennsylvania, where tap water was used as the feed for 2500 hours. A 25-micron filter was used to separate particulate matter from the feed. The unit performed as expected, rendering 18 gallons per square foot per day of product water with a total dissolved solids rejection rate of 93 percent.

Following this initial testing, the unit was connected to the Lester plant's cooling and sanitary flush water supply, which is drawn directly from the Delaware River with only a coarse-sand initial filtration and no biological treatment. Within hours, the filter clogged enough to collapse. Larger (50-micron) filters were installed with the same result.

The unit was then operated without its filter cartridge to determine the potential effects of more rapid clogging of the membrane from greater amounts of suspended solids in the feedwater, and to study methods of membrane cleaning. The great amount of suspended materials in the raw river water reduced the flux of the membrane to about 60 percent of its clean flux rate in about 10 days. However, the clean flux rate was easily restored in a few hours by soak-flushing the membrane with a detergent feed solution. The unit was successfully operated for 2500 hours using the soak-flush cleaning method as needed. Although the Delaware River feedwater contained over 60,000 E. coli bacteria per 100 cc, the rejection rate exceeded 99.99 percent and there were no harmful effects on the membrane. The unit is still operating as of this writing and has shown no noticeable decline in performance after more than 18 months of service.

Other field test units have been in continuous operation with a variety of contaminated waters, including Schuylkill River water near Philadelphia, and process fluids such as industrial-cleaning waste water with high detergent content. All units have demonstrated successful results with no mechanical failures to date in any of the modules, and membrane performance has been consistently restored by a simple soak-flush cleaning. Where iron-deposit fouling has occurred, brief rinses with hydrochloric acid have restored membrane performance by dissolving out the iron.

The field testing has shown that the Westinghouse tubular reverse osmosis system can operate effectively without prior filtration of the feedwater. Maintenance would be expensive for systems that required frequent filter replacement; in some such cases, the costs of filtration alone could approach the cost of an entire reverse osmosis system.

Applications

Proven and potential applications of reverse osmosis are many and varied. A particularly promising use is treatment of mid-range brackish waters (containing between 1000 and 5000 ppm of dissolved solids) to provide potable water for municipal systems. In addition to removing most of the dissolved salts, the process removes bacteria and viruses, thereby reducing the amount of post-treatment chemicals required. (Representative annual expenses of a 10,000-gallon-per-day brackish water treatment system are discussed at left.

Since reverse osmosis is effective in rejecting multivalent ions, the ions that cause hardness, such as calcium and magnesium, are readily excluded. Economical water softening is important, for example, to the soft drink industry, which requires water suitable for carbonation.

In addition to purifying water, reverse osmosis is a useful tool for reclaiming various fluids in industrial processes. Detergents and other organic solubles such as dyes can often be separated from

Typical Plant Operating Costs

A 10,000-gallon-per-day Westinghouse reverse osmosis system costing $24,500 is assigned an arbitrary amortization rate of 15 percent for this example. Total cost for membrane module replacement, assumed to be required every two years, is $5240. Electrical power for the 7½-hp pump costs 10 mills per kWh, while operating and maintenance expense is about $5 per man-hour. About 3 hours per week are required for maintenance. The unit has a recovery rate of 50 percent (half of the feedwater is converted into product water) and has an availability of 95 percent, or about 345 days per year. The cost of producing a thousand gallons of product water is the total annual operating expense, as derived in the table, divided by the volume of water produced in a year: $7545/(10,000 gal/day x 345 days) = $2.18 per thousand gallons.

Annual Costs

Capital (15% of $24,500)	$3680
Membrane Replacement	2620
Power (7½ hp at 10 mills/kWh)	465
Labor (156 hr at $5/hr)	780
Total	$7545

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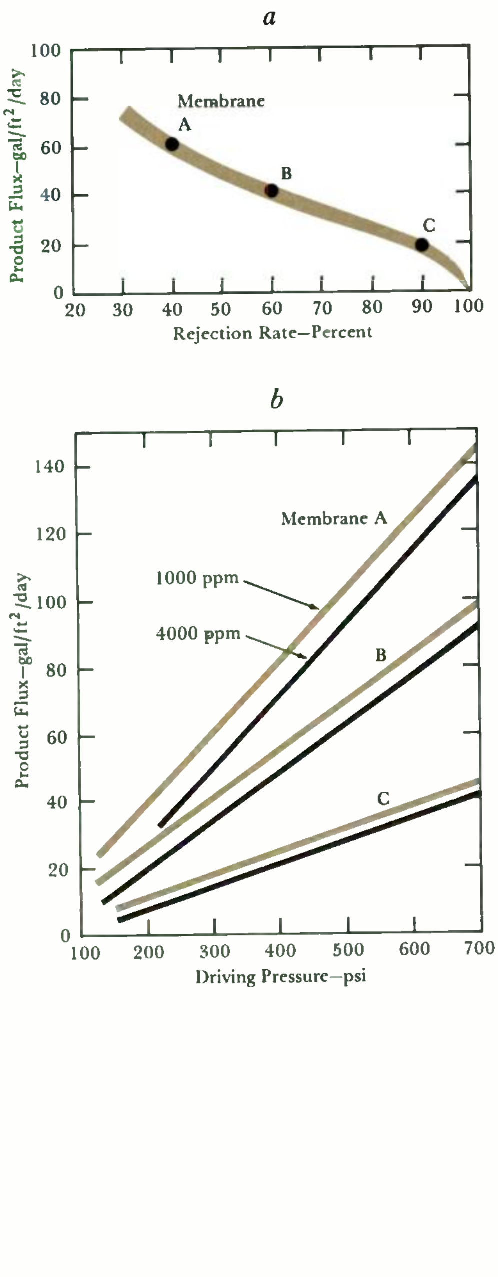

3—Many flux-rejection combinations are available in Westinghouse membranes (*a*). The curve is based on 77 degrees F operating temperature, 300 psi driving pressure, and sodium-chloride feed solution of 1000 parts per million (ppm) concentration. Membrane *A*, for example, provides high product flux when rejecting large ions such as sulfates, while membrane *C* is best suited for rejection of smaller particles such as chloride ions. Product flux varies with driving pressure and feed concentration, as illustrated in (*b*) for the three membranes of (*a*). Color curves represent operation in a 1000-ppm feed solution while the black curves indicate 4000-ppm concentrations. Rejection rates for membranes *A*, *B*, and *C* are 40, 60, and 90 percent respectively.

their waste solutions and either returned to the process cycle or concentrated for more economical disposal. Another example is the reclamation of protein and lactose from cheese whey (a solution of protein, lactose, salt, and water). The protein and lactose that might otherwise be discharged as waste and contribute to water pollution can be reused in food processing. Since reverse osmosis operates without heat, there is minimal chance of altering the taste of food products separated by that process.

Reverse osmosis can sometimes be combined with other types of fluid treatment to maximize system economy. Boiler systems, for instance, generally require feedwater containing far less dissolved and suspended solids than the local water supply provides. The total dissolved solids (TDS) in feedwater for low-pressure boilers must not exceed about 25 ppm, while high-pressure boilers must have ultrapure water in the order of 0.1 ppm TDS. As long as the TDS in the source water is less than about 500 ppm, ion-exchange demineralization is usually the most economical method of furnishing pure boiler feedwater. However, for TDS levels above 500 ppm to about 5000 ppm, the cost of demineralization can be sharply reduced by pretreating the source water by reverse osmosis. Such pretreatment lowers cost by reducing the size of the ion-exchange system and the consumption and disposal of chemicals used to regenerate the ion-exchange resins. In addition, since the reverse-osmosis membrane is an effective barrier against bacteria, the ion-exchange resins are protected from slime-producing bacteria which can impair resin performance.

Another instance where reverse osmosis can be combined with other processes is in the treatment of acid drainage water from coal mines. The contaminated fluid, containing dissolved solids in the range of 1000 to 10,000 ppm, is passed through a reverse osmosis unit as pretreatment. Product water of about 500 ppm TDS or less is extracted from the unit while its blowdown (10,000 to 50,000 ppm TDS) is fed to an evaporator concentrator. The concentrator's product water contains about 5 to 10 ppm TDS, and its blowdown (500,000 to 900,000 ppm TDS) feeds a crystallizer that reduces the contaminants to dry solids. Reverse osmosis pretreatment so greatly reduces the cost of evaporation that, in some cases, the recovery value of the dry minerals can offset a portion of the operating costs.

Some water-short areas such as southern California are seriously considering the reclamation of potable water from municipal waste waters. (Generally, municipal sewage undergoes two treatments: primary, which is a settling process, and secondary, which reduces the biological oxygen demand of the sewage.) The municipalities often pipe their secondary-treated sewage to the sea and pipe in pure water from hundreds of miles away. Use of reverse osmosis would reduce the secondary sewage volume to from 10 to 20 percent of its present level before being discharged, the remainder being product water that could be further purified and returned to the municipal system. This method of reclamation has been proven technically and economically feasible through extensive testing in cooperation with the Sanitation Districts of Los Angeles County in Pomona, California.

Direct treatment of primary sewage is also being investigated.

While reverse osmosis plants should find wide usage in municipal and industrial systems, smaller units are being developed for the home. Already available is a kitchen unit that supplies drinking and cooking water. (See *Reverse-Osmosis System for the Home Purifies Tap Water*, p. 127.) A 400-gallon-per-day system is being developed for complete home water treatment.

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Automatic Control of Aircraft Electrical System Reduces Wiring and Improves Reliability

Manvel A. Geyer
Dwayne F. Rife

An improved distribution system combines remote load control and indication, signal multiplexing, and programmable control logic to reduce system cost, system weight and complexity, flight-crew work load, and the possibility of human error in switching.

Conventional practice in aircraft electrical systems has been to locate the load buses in the cockpit area to give the crew direct access to the thermal circuit breakers that protect circuits. That practice requires running heavy electrical feeders from the generators (on the engines) to the cockpit—a run that may be 150 feet or more—and running power wiring from the buses to all the loads.

However, only about a fourth of the electrical power is used in the cockpit area; the rest is used at other locations in the aircraft. Therefore, one of the features of the new distribution system described here is relocation of the major distribution buses closer to the major loads. It saves wiring and thereby saves weight, because feeders from the generators to the buses and wiring from the buses to the loads are shortened considerably.

Relocation of the buses, however, necessitates a means of remotely controlling circuit protective devices and indicating their status. Wiring is needed for that purpose, but it is minimized by multiplexing the control and indication signals. Wiring is further reduced by substituting solid-state logic for mechanical relay logic, which is now common in aircraft systems for such control and sequencing functions as extending and retracting the landing gear. That improvement also does away with a large source of failure and maintenance cost—the mechanical relay logic.

Moreover, system growth and modification are greatly simplified by making the solid-state logic programmable, that is, introducing a computer into the system. The computer permits automatic control and load management so as to reduce the need for manual supervision and the consequent possibility of human error, especially during anomalous system operation. The computer also makes system self-test diagnostics possible to further simplify maintenance.

The automatically controlled electrical system (ACES) was developed by the Westinghouse Aerospace Electrical Division with the Systems Development Division. Demonstration hardware has been built, software has been written, and flight tests of the system are planned.

Potential benefits of the system include reduced wiring weight and complexity, reduced manual supervision, lower overall cost, less susceptibility to human error, fewer bulkhead penetrations, simplified maintenance, programming of loads under conditions of low power availability, and greatly simplified means for system growth and modification.

ACES is currently being developed for aircraft and spacecraft applications, but use on submarines and surface ships is also foreseen. The concept may eventually find applications in office buildings and in industrial plants, especially for the continuous process industries.

System Concept

In an aircraft or spacecraft, the flight crew must be able to turn electrical loads on and off and must have quick access to the thermal circuit breakers that protect the circuits. Conventional practice requires many miles of electrical wire (Fig. 1a). (The Concorde, for example, has 150 miles of electrical wiring for distribution, control, and indication.) The system may have 500 to 1000 load circuits requiring thermal circuit breakers.

The 75 percent of the power that is not used in the cockpit area can be remotely controlled from the cockpit as shown in Fig. 1b. Such a system is used in the latest generation of commercial jet aircraft. In it, power feeders go to buses located at electrical "centers of gravity" for various portions of the aircraft, and remotely controlled circuit breakers are located on the rearward buses. Those breakers are thermal circuit breakers with electromagnets to open and close them. They are remotely controlled by applying 28-volt dc power to the control terminals, which requires running a small electrical wire to the cockpit for each breaker. The status of each must be known, so a second wire must be run to the cockpit to indicate if the breaker has tripped. Since both are power-carrying wires, they must also be protected by small thermal circuit breakers.

A comparative study of such a distribution system and the conventional system was performed with information provided by the Boeing Company on electrical loads, load location, wire size and weight, and circuit breaker size and weight for a new transport aircraft design. The study showed that more feet of wire and more thermal circuit breakers would be used in the remotely controlled system, but that an overall weight saving of approximately 160 pounds would result from the much smaller wire required for control.

1—Conventional practice in aircraft electrical systems (*a*) has been to locate all load buses in the cockpit area to give the crew direct access to the protective thermal circuit breakers. Heavy feeders must be run from the generators to the buses, and power wiring from there to the loads. The limit switch shown indicates the mechanical relay logic conventionally employed to sequence and control electrical loads.

System weight can be saved (*b*) by centralizing main power buses and using remotely controlled circuit breakers (RCCBs) for load switching and circuit protection. Although this method requires more wiring and circuit breakers, there is an overall weight saving because much of the wiring is the smaller wire required for control and indication purposes.

In the new automatically controlled electrical system (*c*), both control wiring and power wiring are minimized. Control and indication signals are transmitted between the cockpit and a number of remote power controllers (RPCs) via remote input/output (RIO) units and a multiplexed data bus. The distribution control center (DCC) is a "switchboard" for properly routing signals between control and indication devices. Limit switches and other mechanical relay devices are replaced by transducers that provide signals to the distribution control center, where the logic for sequencing and automatic control is contained. Switch-indicator modules (SIMs) provide one means of trip and load indication as well as manual command input.

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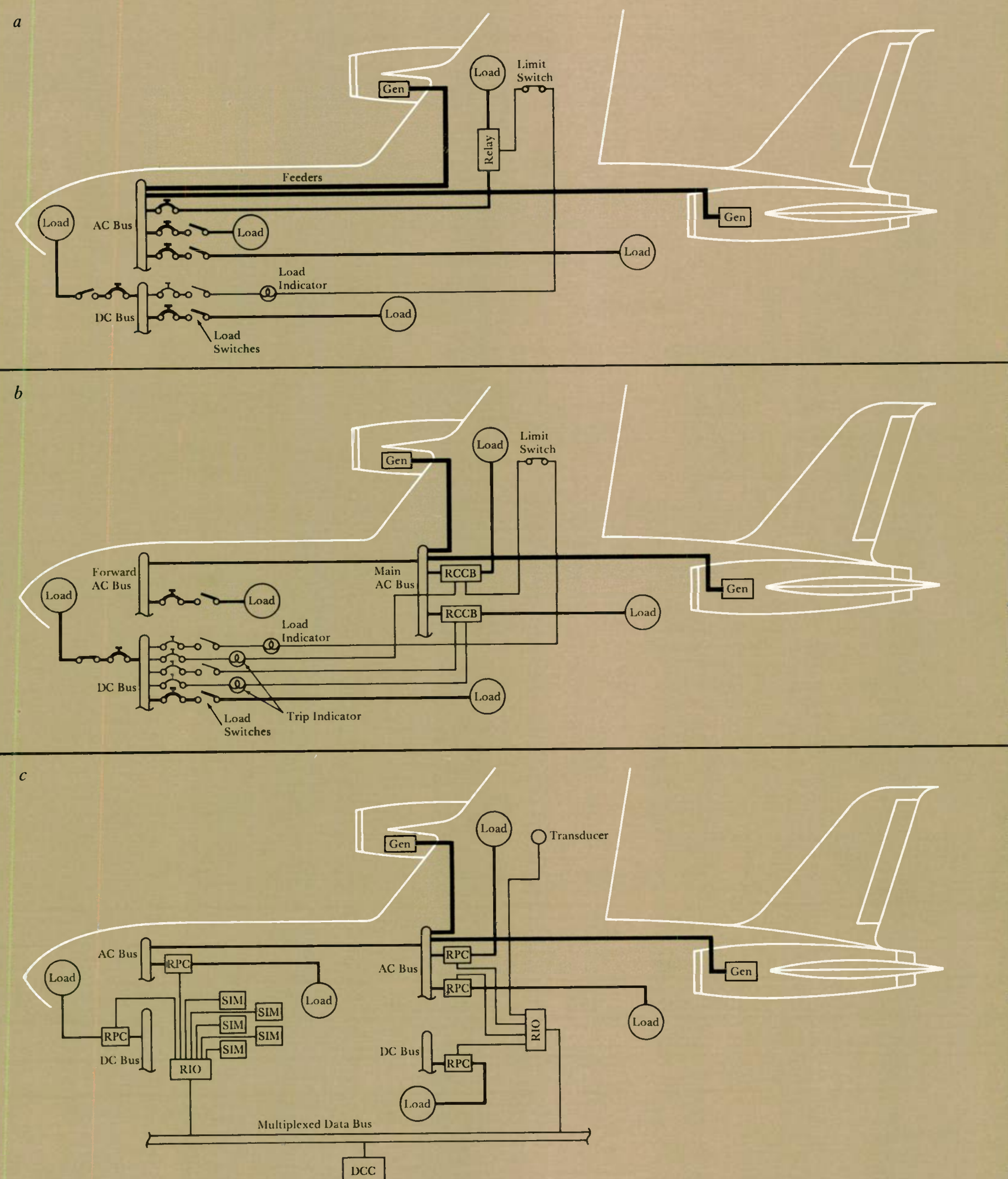

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Additional studies then were performed to determine what savings and advantages might be possible from applying other concepts, including multiplexing and the U.S. Navy's SOSTEL (Solid State Electrical Logic) concept. In that concept, mechanical power-switching devices such as thermal circuit breakers, relays, and limit switches are replaced by solid-state power-switching devices and transducers. Because such devices are compatible with solid-state logic elements, the relay logic conventionally employed can be replaced by solid-state logic. The SOSTEL concept also encompasses the use of solid-state remote power controllers that perform both remote load switching and circuit protection functions as remotely controlled circuit breakers do. The transducer signals and the control and indication signals for the remote power controllers readily lend themselves to multiplexing.

Those studies led to the definition of ACES (Fig. 1c). ACES requires much less control wiring than does the remote control system of Fig. 1b. It employs solid-state remote power controllers and solid-state transducers insofar as it is economically and technically practical to do so. The use of mechanical switching devices is not precluded, since some power levels encountered in aircraft applications cannot yet be adequately handled by solid-state devices; generator circuit breakers and bus control breakers, for example, probably will be electromechanical until adequate solid-state switching devices are developed.

System Operation

The logic required for load control and sequencing, self checkout, and automatic load shedding is contained in a computer called the distribution control center. Signals from transducers and switch-indicator modules are transmitted to the distribution control center on a multiplexed data bus via remote input/output units. Logic equations are solved by the computer, and command signals are transmitted on the multiplexed data bus specifying which remote power controllers are to be turned on or off. The remote input/output units, which provide the interface between the data bus and the remote power controllers, decode the command signals and route them to the appropriate remote power controllers, which provide the desired load switching functions.

If a remote power controller senses an overload condition, it protects the wire by tripping open. It also transmits an open indication signal to the distribution control center via a remote input/output unit and the data bus. After a programmed time delay, the distribution control center automatically transmits a reset signal to reclose the remote power controller. If the fault has cleared, the remote power controller remains closed and power is restored to the load. If the fault persists after a programmed number of automatic reclosures, the distribution control center transmits a trip indication signal to the cockpit indicating which remote power controller has tripped. The remote power controller remains tripped until manual action is taken to reset. The number of automatic reclosures (from zero to two) is programmed in the distribution control center for each remote power controller; it can be varied depending on load criticality and other criteria.

Turn-on and turn-off commands are manually provided to the system by switches and switch-indicator modules located on the craft's subsystem control panels. Tripped remote power controllers are reset manually by switching to the *off* and then back to the *on* position. The indicator portion of a switch-indicator module can be used to indicate a tripped remote power controller or some other state, such as that the load is turned on.

An additional man-system interface is provided by a data entry and display panel (Fig. 2). It provides single-point entry and display capability and requires much less space and weight than the present large thermal circuit breaker panels. The panel's "RPCs Tripped" lamp comes on if one or more remote power controllers have tripped. If any loads have been shed by the load management function, the panel indicates that by lighting a lamp. When a controller is tripped, a numerical readout tells the crew exactly which one it is; if more than one is tripped, their numerical codes are displayed in subsequent readouts by depressing the "Clear/Update" button. The numbered pushbuttons are for addressing particular controllers. An addressing error turns the "Invalid Address" lamp on. Once a controller is properly addressed, it can be opened or closed by using the buttons at the right side of the panel.

System self checkout is under software control. It is actuated automatically during every control system power-up or manually by switch command. Any system malfunction is found and its location displayed on the panel.

Redundant construction prevents single failures from causing loss of control of more than one remote power controller. For example, several data buses are used, one in operation and the rest on standby. The interior of the remote input/output unit is redundant down to the output buffers. The distribution control center interrogates the system during operation, checks for a malfunction, and chooses a good channel; thus, the system can tolerate at least one failure in all but one of the channels and still be operational. A buffer failure causes loss of control of at most one remote power controller.

Simultaneous switching of loads with high inrush current (which might cause large system transients) can be prevented and the loads switched on in time sequence. The loads involved and the switching order and time intervals are under software control. Also, if a portion of the electrical generating capacity is lost, the system automatically sheds load

***Photo*—Demonstration equipment simulates part of an aircraft electrical distribution system to show how power and signals are handled in the automatically controlled electrical system. In the front row, the first four units (stacked in pairs) are switch-indicator modules, the next two are remote power controller simulators, the one partly hidden by the man's face is the data entry and display panel, and the rest are additional remote power controller simulators and another switch-indicator module. Units in the back row are, left to right, the distribution control center, four remote input/output units, and a program loader.**

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(in accordance with a programmed priority schedule) to prevent overloading of the electrical source.

Different load priority schedules are likely to be required for different flight modes, so the system software is designed to handle up to four different load priority schedules that can be selected according to flight mode. The system can also be reprogrammed with a program loader and console to accommodate logic changes and load-priority changes for different applications (Fig. 3). The program loader includes a tape reader.

Remote Power Controllers—The solid-state remote power controllers switch power to a load on or off on command of a control signal. They also protect the electrical circuit by tripping open when an overload is sensed. The controllers are made up of deposited resistor and conductor films and semiconductor chips attached to a substrate.

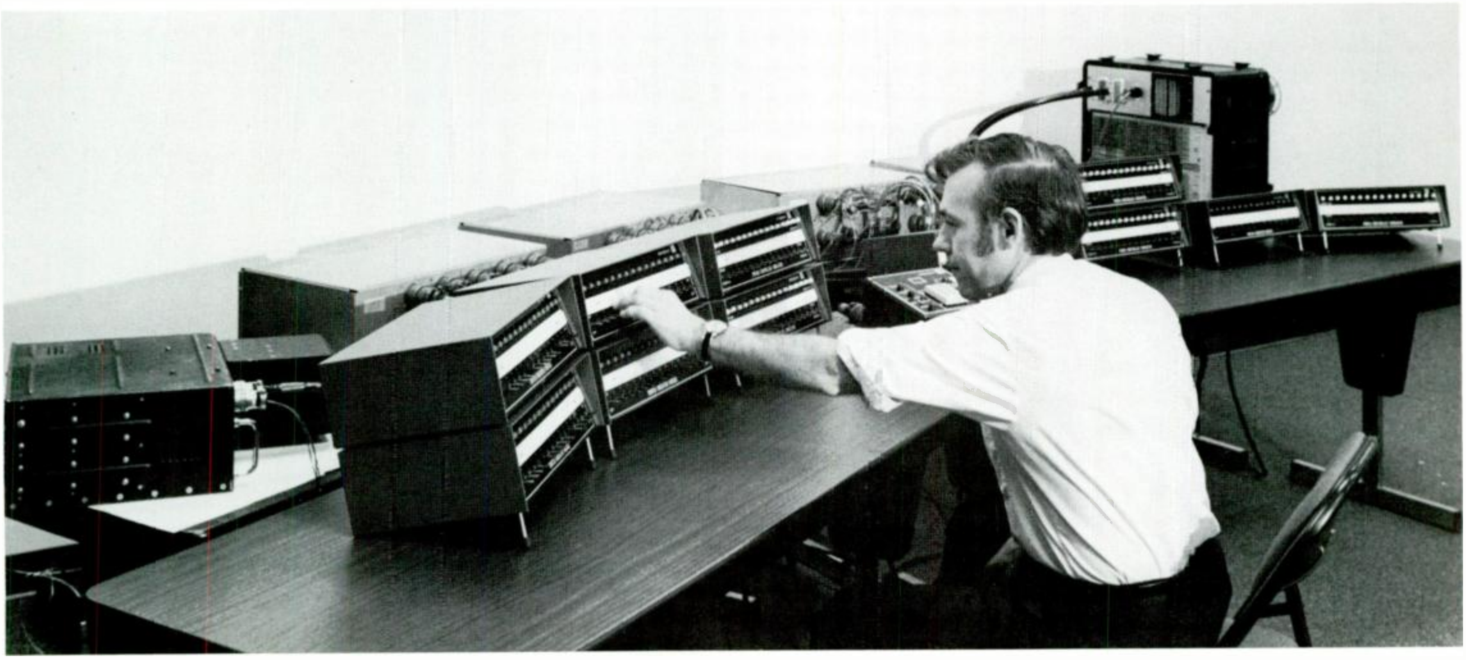
Remote power controllers for dc loads consist of a power transistor (the load-switching device), current and voltage sensors, and a circuit that provides on, off, current-limiting, and trip control. The ac controllers have two thyristor power switches, a current sensor, and a control circuit that provides a shaped trip characteristic as well as on-off control.

Multiplexed Control— A time-division multiplexing technique, as opposed to a frequency-division technique, was selected because the bandwidth required for frequency-division multiplexing would be prohibitively large due to the large number of channels required (at least one for each remote power controller, transducer, and switch). Also, time-division multiplexing is compatible with digital computers and is generally less complex and less expensive for the types of signals processed by this system.

The two extremes of time-division multiplexing are the round-robin method and the random-access method. The round-robin method requires that the system be synchronized and that each device serviced by the system be assigned a specific time interval in which to transmit and receive. It is relatively susceptible to electrical noise that might cause spurious data transmission, an intolerable occurrence where lives depend on reliable control of electrical power.

The random-access method requires that each device have a unique coded address. Each device must be addressed before it can be serviced. The data transmitted by the system to each device usually consists of a single bit—a logical one (*on* signal) or a logical zero (*off* signal). As many as 16 bits would be required to provide the address code for a device. This total of 17 bits required to transmit a single bit of information is extremely wasteful and, for servicing a large number of devices, would drive the bit rate up to an intolerable level from the standpoint of electrical noise susceptibility.

A compromise method called random-access batch processing was selected. In it, each remote input/output unit instead of each device has a unique address, and the devices connected to each remote input/output unit are serviced sequentially as in the round-robin method after the unit has been addressed. This arrangement allows devices to be serviced as necessary instead of once every update cycle as with the round-robin method. It also permits up to 64 devices to be serviced with a single address, which is much less wasteful of bits. Indeed, the method lowers the bit rate to 40,000 bits per second from the 500,000 bits per second required if the random-access method were employed.



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The data bus is a full duplex bus; that is, there are separate buses for transmitting and receiving. The Data I bus, consisting of a twisted shielded pair of wires, transmits information from the distribution control center to the remote input/output units. The distribution control center receives information from the remote input/output units on the Data II bus, also a twisted shielded pair. A third twisted shielded pair, called Strobe, transmits a train of 40-kHz pulses that provide the synchronization required by the remote input/output units to service their devices in a round-robin manner.

Data transmission reliability is enhanced by transmitting, on one of the wires of each twisted/shielded pair, the complement of the signal that appears on the other wire; that is, when a positive pulse is transmitted on one, a negative pulse is transmitted on the other. Differential detection of these signals by the distribution control center and remote input/output units provides virtual immunity to electrical noise and to high common-mode voltages, which could cause spurious signals on the bus. Any electrical noise induced on the bus appears the same on each of the wires of the twisted shielded pair; since the noise signals are the same and not complementary, they cannot be detected in the differential mode and are therefore ignored by the system.

Reliability is further enhanced by using an echo check to make certain that the remote input/output unit that receives the data is the one addressed. The distribution control center transmits on Data I the address code for the remote input/output unit connected to the devices to be updated. The unit that recognizes this coded address responds by transmitting its address code to the distribution control center on Data II, and the distribution control center compares the address code transmitted with the one received. If they are the same, the distribution control center then transmits the updated command data to the remote input/output unit on Data I and receives the unit's updated status data on Data II. If the two addresses are not the same, the data transmission is aborted.

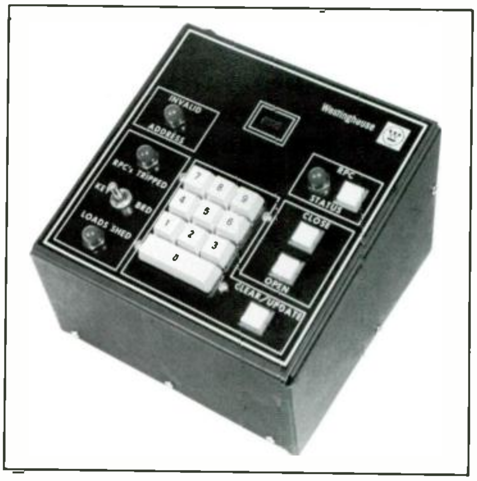
Distribution Control Center—This is a small general-purpose military type computer of modular design. It has standard transistor-transistor logic composed of integrated-circuit devices with medium-scale integration complexity, and its memory is expandable from 4000 to 64,000 words in any combination of magnetic-core, plated-wire, or semiconductor integrated-circuit memory. Computing speed is over 300,000 instructions per second with magnetic-core memory, and more than double that figure with semiconductor memory.

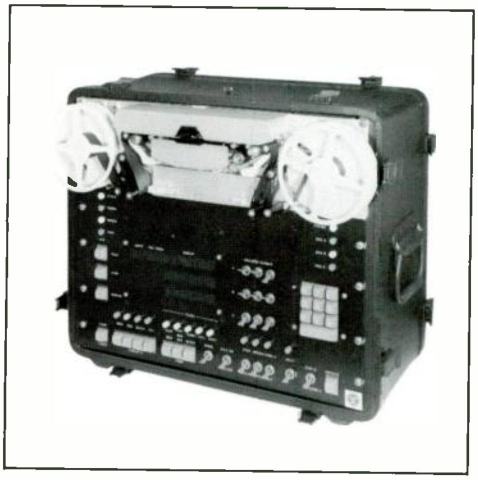
The memory requirement for the system is approximately a thousand words per remote input/output unit. This requirement includes allowance for all software functions. In an application, the memory would probably be a combination of "read only" and "read/write" semiconductor memory and a nonvolatile "read/write" magnetic-core or plated-wire memory. The program memory must be made nonvolatile so the computer can withstand power interruptions without program loss.

It may be desirable in some applications for ACES to interface with a central data management system for control or display purposes, or both. This capability can be added to the distribution control center simply by installing an input/output unit to properly mate with the central system data bus and by making appropriate software changes.

Remote Input/Output Units—Each unit accommodates up to 64 transducers, switch-indicator modules, remote power controllers, or any combination thereof. Each has 64 command outputs and 64 status inputs. The control outputs provide signals that activate a remote power controller or the indicator portion of a switch-indicator module. The status inputs accept signals from transducers, limit switches, the switch portion of a switch-indicator module, and the status indicator output of a remote power controller.

Each remote input/output unit is assigned a unique address code via a permanently wired mating connector. This means that all units are the same and therefore interchangeable, an arrange-





2—(*Top*) Instead of a large number of thermal breakers in the cockpit, the crew of an aircraft equipped with ACES would have only a data entry and display panel.

3—(*Bottom*) The program loader and console is a piece of support equipment that provides for manual checkout of the distribution control center and its operational software. It contains a paper tape reader for loading the distribution control center memory.

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ment that provides obvious advantages in maintenance and also in spares inventory.

Each remote input/output unit is constructed redundantly so that it is essentially several input/output units, each driven by a separate data bus. Each of the units is completely self-contained with its own power supply; thus, a failure in one does not propagate into another and has no effect on system performance. The outputs of the units are joined at a buffer that drives the remote power controllers or other connected devices. Each output channel has its own buffer unit, so a failure in a buffer affects only one of the 64 outputs. Each buffer is current limited so that the output can be short-circuited indefinitely without disturbing the rest of the control system.

System Software

The key to system operation is the software. It establishes the distribution system configuration; that is, what loads are under the control of which switch-indicator modules and transducers and the logic that governs their control. It also establishes the automatic aspects of the system such as self-test, start-up sequencing, and load management.

All of these features are under the control of the system designer when he writes the system program. His control equations are Boolean in nature and look much the same as FORTRAN programming. An attempt has been made to keep the interface between the system designer and the software as simple as possible. In the mnemonics of the system, for instance, "CRPC16=SIMS16" means that the command signal to remote power controller 16 will be a logical one if, and only if, the status of switch-indicator module 16 is also a logical one. "SIML16=TRPC16•FRPC16" means that the lamp of switch-indicator module 16 will turn on if, and only if, the twice-tripped location 16 and the first-tripped location 16 are both logical ones.

The automatic ground test checks for faulty data buses, faulty remote input/output units, and faulty remote power controller control circuits. This test requires that 28-volt power be applied to the distribution control center and the remote input/output units but no power to the load buses of the system. The results are displayed in an error code on the data entry and display panel. The test for failed units requires only four error codes, but nine are generated for diagnostics of some of the internal faults of the remote input/output units and remote power controllers. The test even indicates, in the case of a faulty data bus, between which remote input/output units the fault lies.

The start-up sequence is also under software control. Usually only 15 to 20 percent of the loads are under switch control; that is, manually controllable with a switch-indicator module. On start-up, the setting (*on* or *off*) of remote power controllers controlling those loads is no problem since the positions of the switch-indicator modules provide that intelligence. The intelligence for setting the other loads is provided by the software. At the discretion of the system designer, the other loads can be set in the same position they were in when the craft was powered down, or they can be set in accordance with a predetermined schedule. Such a schedule is similar to the manual setting of loads via a checklist as is currently done in powering up an aircraft, but with this system it is done automatically with the checklist a part of the software. After the start-up sequence is complete, control is relinquished to the normal system operation software.

Load management consists of three primary functions; shedding of loads in accordance with an established schedule whenever load requirements exceed system capacity, sequencing of loads that have high inrush current to prevent large system transients from occurring because of simultaneous load switching, and automatic resetting of tripped remote power controllers.

The software allows for establishment of up to four load priority schedules, each having four priority levels. Each schedule establishes the load priorities for a particular flight mode (such as take-off and landing, subsonic cruise, and supersonic cruise). For example, landing-gear actuators would be very high priority loads in the take-off and landing mode but very low priority in supersonic cruise.

The system designer establishes the priority level of each load for each mode when he writes the system program. He also establishes which loads are to be sequenced on, the time delays involved in the sequencing, which remote power controllers are to be automatically reset, the number of automatic resets (up to two), and the time delay between automatic resets for each remote power controller.

Conclusion

System studies have shown that weight can be saved in large aircraft by moving the power distribution buses out of the crew area and closer to the loads. Such a change requires circuitry for control from the crew area and for status indication there, but that circuitry can be minimized in weight by signal multiplexing and by use of solid-state logic.

Use of a small computer to perform the logic simplifies system growth and modification by making the logic readily reprogrammable. It also permits incorporation of automatic control, load management, and self testing for additional advantages in system operation.

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The Integral-Horsepower AC Electric Motor, 1890 to 1980

R. F. Woll

Motor development has been vital and progressive over the years, and it gives every promise of remaining so.

The induction motor, since its inception in the late 1800's, has continually benefited from advances in design, manufacturing, and materials. Those advances have resulted in notable improvements in insulating components and insulation systems, gains in mechanical protection accompanied by improved cooling, better bearings and lubrication, and dramatic reductions in physical size. The technology has by no means reached its limits, so motors are still being improved in ways that permit some realistic predictions about what the integral-horsepower motor (approximately 1 through 200 horsepower) will be like 10 years from now.

Although the illustrations and detailed comments in this article apply to Westinghouse motors, the brief history presented is typical in a general way for the motor manufacturing industry as a whole.

The Early Motors

The first commercial line of induction motors was designed, built, and marketed by Westinghouse in 1890 (Fig. 1). The motor was rather ungainly but was a great innovation, marking the beginning of the end of the old mechanical power systems of the Industrial Revolution—central power sources driving long line shafts from which individual machines were driven by their own pulleys. The induction motor made individual drives for each machine (and even for separate elements of a single machine) practical and economical.

The 1890 motor offered virtually no mechanical protection to its working parts and had no particular ventilation system. Improved versions manufactured in the late 1890's led to the 1910 model, which is much more recognizable as a motor (Fig. 2). Its frame proper was a completely enclosed structure; the familiar double end ventilation system had emerged, but in a somewhat unusual form. All air openings were in the end brackets—inlet openings in the radial faces and outlet openings in the axial faces. Although the motor was much better enclosed than the 1890 model, the large number and size of openings detracted from the protection afforded by the frame to stator windings and operating personnel.

The 1920 motor also was double end ventilated (Fig. 3). During its manufacturing life span, the use of die-cast aluminum for the rotor cage was initiated to supplant brazed copper bars and end rings in high-production motors. Die-cast rotors were lower in cost, mechanically stronger, and faster to produce.

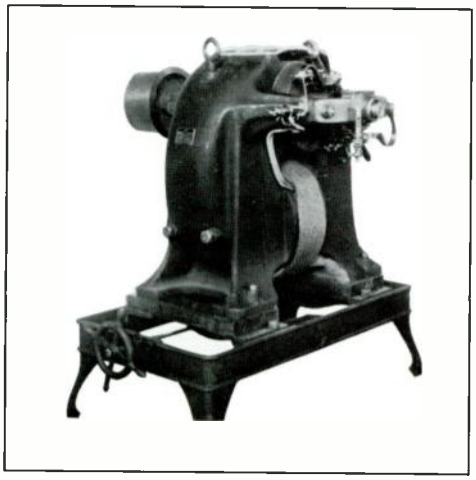
The motor of 1930 did not differ greatly in general appearance: it was still wide open, with no semblance of protection against dripping liquids or solid particles. It was, however, the first "NEMA" motor, for the National Electrical Manufacturers Association had standardized the basic mounting dimensions for integral-horsepower motor frame sizes and assigned standardized horsepower ratings to the frame sizes. Although the standards are completely voluntary in their application, they provide major benefits to both users and manufacturers of integral-horsepower ac motors.

More Recent Motors

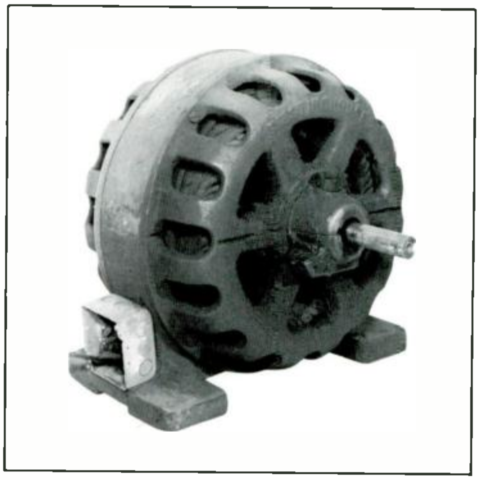
Further modernization in the 1940's made the open motor dripproof, with its housing offering substantial protection to the internal parts (Fig. 4). Also, the sleeve bearing was supplanted by the ball bearing, a topic discussed later. This motor was single end ventilated, with cooling air drawn in one end bracket, passed axially through the frame, and discharged from openings in the other bracket.

In the smaller sizes of the integral-horsepower range, vanes cast integral with the rotor end rings propelled sufficient cooling air; for larger sizes, separate fans were required. Single end ventilation is a somewhat less effective cooling system for open motors than double end. However, cooling of the 1940 motor was adequate because of gains in insulating components and practices, another topic discussed later.

The 1950 motor was the U-frame motor of the immediate past, a modern looking machine retaining and enhancing its predecessor's dripproof protection (Fig.



1—First commercial ac motor was this 1890 Westinghouse machine. Its wide-open construction didn't incorporate a ventilation system as such, and it left something to be desired in protection of the bearings, stator windings, and rotor. Improved machines soon followed.



2—Type CCL 1910 motor was photographed as it was retired early this year. It had been used in a machine shop from about 1913 to 1960 to drive several machines via an overhead lineshaft; then, to soften the transition to retirement, it was assigned to blower-drive duty.

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5). It too was primarily a ball-bearing motor. Small sizes had single end ventilation, but larger sizes were double end ventilated with frame discharge air openings limited to the area near the feet.

Among the factors in the rapid evolution from the 1890 motor to modern motors were improvements in insulation and in bearings.

Class-A Insulation — Up through the U-frame motor of the 1950's, standard motors had Class-A insulation systems (105 degrees C hot-spot temperature). Many improvements in Class-A materials and methods developed; among the earliest, and one that resulted in a major gain in productivity, was the switch from form-wound to random-wound coils for low-voltage stator windings (600 volts and below). Since slot openings for random-wound coils are much narrower than for form-wound coils, a gain in power factor was also realized.

Another outstanding improvement was reduction of the insulated diameter of magnet wire. Up to the mid-1920's, the wire used was double cotton covered. No. 18 wire, for example, (0.040-inch diameter bare) had an insulated diameter of almost 0.050 inch. Then single-cotton-covered enameled wire was introduced; it was lower in cost, had distinctly improved insulating characteristics, yet was smaller in insulated diameter. The next diameter reduction, in the early 1930's, was made by replacing the cotton with paper. Paper also had higher dielectric strength than cotton, and it did not have the tendency to fray. Finally, from the experience gained with wire enamels on the cotton- and paper-covered enameled wires, the present standard double-build enameled wire evolved in the early 1940's. The insulation coating is vastly superior, having better mechanical and electrical strength and providing still further reduction in insulated wire diameter—down to 0.044 inch for No. 18 wire.

This brief history of Class-A magnet wire is an example of truly worthwhile development, because continually lowering wire costs were accompanied by continually improving properties. The reduction in insulation thickness gave two important side benefits: it permitted a relatively greater copper section in a given motor, and it lowered the thermal gradient between copper and cooling air. Both benefits contributed in a major way to motor size reduction.

Similarly, other insulating components have become thinner, mechanically and dielectrically stronger, and easier to insert. In the late 1930's and early 1940's, confidence in the quality of magnet-wire insulation had risen to the point where taping of the individual stator end turns was no longer necessary, eliminating a time-consuming winding operation and a detrimental thermal barrier.

In about the mid-1940's, manufacturers introduced a seemingly minor innovation, a change from flat- to round-bottomed stator slots, that provided a dual benefit. It avoided the need for creasing the slot cell at the slot corners, which had tended to weaken the dielectric strength of the ground insulation, and it slightly increased the copper section in a slot of given area because individual winding wires conformed better to the round-slot geometry.

Class-B Insulation — Before today's T-frame motors, standard integral-horsepower motors did not have Class-B insulation (130 degrees C hot-spot temperature), but special motors from 1930 on frequently did have it. As with Class-A magnet wire, the insulated diameter of Class-B wire was reduced with time—

3—Early version of Type CS 1920 motor had a frame consisting of two rings joined by heavy cast feet riveted to them. Cooling air was drawn in through large openings in each end bracket and discharged through clearances between each end ring and the stator core.

4—Type CSP motor of 1940 vintage had a dripproof housing for greatly improved protection of windings. It was single end ventilated and had sealed prelubricated ball bearings instead of the sleeve bearings that had been standard in the earlier motors.

5—U-frame motors came out in mid-1950's. This Life-Line A machine was single end ventilated in the smaller sizes; the ventilation opening in each end bracket is virtually invisible, being confined to the lower quadrant. Larger sizes were double end ventilated.

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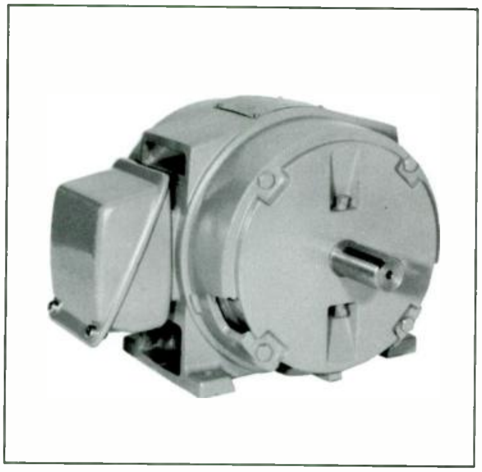

6—(*Top*) Today's T-frame motors are represented by this Life-Line T dripproof machine. It has double end ventilation in all sizes and double-shielded regreasable ball bearings. Horsepower ratings per frame size are about twice those of the U-frame motors.

7—(*Bottom*) Totally enclosed fan-cooled (TEFC) motor, a 1960 Life-Line T unit, has externally finned cast-iron frame and a fan that blows air over the fins. These motors are used where the environment is too severe for open motors.

down to 0.044 inch for No. 18 wire. The size reduction had the same benefits cited for Class-A wire, and the double-build enameled Class-B wire gave a primary impetus to the T-frame rerate of the mid-1960's.[1,2]

The gain in mechanical and dielectric strength from the asbestos-covered wire of 1930 to double-build enameled wire of 1960 was even greater than the corresponding gain from double-cotton-covered to double-build enameled Class-A wire. Double-build enameled wires in both Class-A and Class-B versions have about the same mechanical and dielectric strength, but the old Class-B asbestos-covered wire was a marginal product at best. Asbestos, being a mineral, contained conducting fragments that frequently caused turn-to-turn shorts; the asbestos-covered wire, as well as other old Class-B insulating materials of asbestos, was also weak mechanically and frequently was damaged during winding. Class-B double-build enameled wire has completely overcome those weaknesses, and it has the additional virtue of Class-F thermal capability.

Along with the enameled wire, other Class-B insulation components matured in the late 1950's. They were largely of synthetic materials that were thin, had remarkable mechanical and dielectric strength, were virtually impervious to moisture, and in many instances had thermal capability well beyond Class-B requirements.

Bearings—The earliest motors all had sleeve bearings. The 1930 motors were predominantly sleeve-bearing types, but ball bearings were available as an extra-cost option. Early sleeve-bearing designs continually had problems of oil leakage, so, in about 1925, Westinghouse developed the "sealed-sleeve" bearing to put an end to the troubles.

The ball bearings first used were of the open type, and thus more vulnerable than later ball bearings to entrance of contaminants. By the mid-1940's, for integral-horsepower motor sizes, the situation had reversed in that ball bearings had become standard and sleeve bearings were the extra-cost option, a condition that still prevails.

Our ball-bearing motors of the 1940's and 1950's had sealed prelubricated bearings and had no provision for normal in-service relubrication. That kind of bearing for electric motors was developed in about 1930, when Westinghouse originated a line of open lint-free textile motors. Those motors had a skeletonized frame and end brackets, with particular emphasis on keeping all surfaces as smooth and rounded as possible and on providing large unrestricted passages for the double end ventilation flow of cooling air. Stator end turns were wrapped with circumferential layers of tape and then spread with a compound that was rubbed smooth, giving a finished appearance quite similar to today's encapsulated windings.

The purpose of those features was to permit free passage of lint through the motor and to avoid build-up of lint on any part of the motor surface. The commonly used sleeve bearing was unacceptable, mainly because its projecting oil cups would collect lint, the inevitable oil drips would cause lint to collect on any motor surface so affected, and oil stains and vapors were incompatible with the general cleanliness desired to prevent soiling of the textiles being woven. The same objections, though to a lesser degree, applied to conventional open regreasable ball bearings. Thus, bearing manufacturers and Westinghouse collaborated in developing the sealed prelubricated ball bearing for textile motors. It proved an immediate success, and, by the mid-1940's, field experience with it justified our extending its use to our standard motor line and continuing its use through the 1950's in our U-frame motors. (It should be noted that the bearing development was largely dependent on simultaneous development of a suitable lubricating grease: since the grease could not be replenished in service, it had to have stability, oxidation resistance, and long life.)

By 1960, however, commercial and economic factors led to our discontinuing the use of sealed prelubricated bearings. Users of our motors were divided in their acceptance of the bearing. Some were highly enthusiastic over the lower main-

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Table I. Approximate Dates of Major Developments

General	1880	1890	1900	1910	1920	1930	1940	1950	1960	1970	1980
Tesla's First Motor	●										
First Commercial Line		●									
First NEMA Frames						●					
Electrical											
Double-Cage Rotors (more torque per ampere at locked rotor)					●						
Die-Cast Aluminum Rotors					●						
Round-Bottom Stator Slots							●				
Simple Computer Programs for Motor Design								●			
Sophisticated Computer Programs for Motor Design									●		
Mechanical											
First Explosion-Proof Motors					●						
Leakproof Sleeve Bearings					●						
TEFC Enclosure Widely Used						●					
Dripproof Enclosure Replaced Open as Standard Ball Bearings Replaced Sleeve as Standard							●				
Insulation and Windings											
Class-B Insulation Introduced				●							
Random-Wound Coils Replaced Form-Wound for Low Voltage (<600)					●						
Class-A Enameled Wire							●				
End Turn Taping Eliminated							●				
Class-H Insulation for Ultrasevere-Duty Motors							●				
Class-F Insulation								●			
Class-B Insulation in Common Use, Including Enameled Wire									●		
Machine Winding for Polyphase Stators									●		
Class-F Insulation in Common Use, Including Enameled Wire									●		
Aluminum Wire in Selected Ratings									●		
Class-B Insulation in NEMA Standard-Line Motors									●		
Probable First Use of Class-F Insulation in NEMA Standard-Line Motors											●

tenance costs inherent in elimination of the need for in-service greasing and over elimination of the possibility of over-greasing, perhaps the largest single cause of bearing failure. Other users, especially in industries involving either bad environmental conditions or continuous line processing, were equally insistent that the capability of regreasing motors in service was a vital necessity. Moreover, as use of Class-B insulation expanded, the resultant higher bearing operating temperatures approached the thermal capability of the grease developed for sealed prelubricated bearings. Finally, the prelubricated bearings represented from a few to several dollars added motor cost (depending on bearing size), an added cost that was not recoverable in price.

Therefore, our present T-frame motors have double-shielded ball bearings, with a grease that has thermal capability well beyond Class-B bearing operating temperatures. The double-shielded bearing has most of the benefits and none of the handicaps of the sealed prelubricated bearing: its shield, although not as tight fitting as a seal, serves to keep contaminants out of the bearing, and, although the bearing can be regreased in service, its shield acts as a metering device to help prevent over-greasing. Greasing practices vary widely, depending on service conditions.

In the early 1960's, ball-bearing manufacturers started to use vacuum-degassed steel for balls and races. These "clean steel" bearings have about 45 percent more load capacity for a given life than previous bearings, or about triple the B-10 minimum fatigue life at the same loading. (B-10 life is the life that 90 percent of a group of bearings will exceed without fatigue failure.) Vacuum-degassed bearings are now standard in the motor industry.

Today's Motor

Approximate dates for the major developments in motors over the past 90 years are shown in Table I. Those developments have culminated in today's T-frame motor (Fig. 6). This motor has the advanced Class-B insulation system, double-

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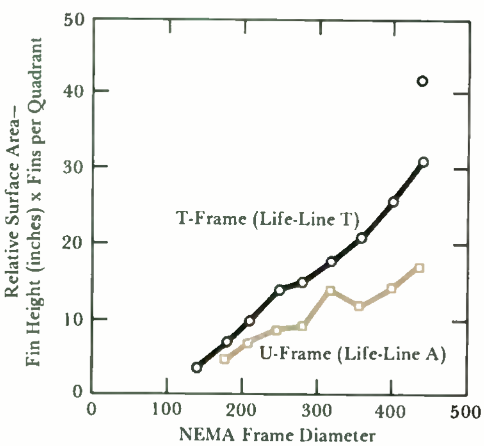
shielded bearings, and construction that combines the protection of modern dripproof enclosures with the high-level cooling of the old 1930 double end ventilated open motor.

High-volume air flow is promoted by ample but safely sized inlet openings in both end brackets; the openings extend a little beyond the lower quadrant but maintain a high degree of dripproof effectiveness. The frame diameter is swelled out slightly (flattened at the bottom for floor clearance) to give more than normal space for air flow between stator core and frame. Outlet openings in the frame complete the cooling circuit. These openings are located not only in the normal area at bottom near the motor feet but also in well protected ports above the frame centerline. The entire cooling circuit is designed to avoid air restrictions at any point, thus assuring high-volume air flow for maximum cooling.

The TEFC Motor—Up to this point I have discussed only open and open-dripproof motors because the first electric motors were available only in the open form. In response to user needs, however, totally enclosed fan-cooled motors have become increasingly popular. They have been a significant factor in the motor business since the late 1920's or early 1930's. Their primary applications are in industries imposing environmental conditions detrimental to a motor's internal parts. Special versions are available to meet Underwriters' Laboratories requirements for explosion-proof and dust-ignition-proof motors.



8—Surface area for cooling was made much greater in Life-Line T TEFC motors that it had been in the previous U-frame motors by increasing the amount of finning. The increase was the main factor in the improved heat dissipation needed when ratings per frame size were increased with introduction of the T-frame motors. The point above the T-frame curve represents a production 440-frame motor with even more than the usual amount of finning.

Totally enclosed integral-horsepower motors, like open motors, have benefited from technological advances. For the past decade or two, the most popular form of TEFC motor has had axial external fins on the frame surface with a shaft-mounted external fan blowing cooling air along the finned surface to dissipate internal heat (Fig. 7). Our present T-frame motors have about twice the horsepower rating per frame size as the preceding U-frame motors. The gains were made (in both dripproof and TEFC versions) by the change from Class-A to Class-B insulation as standard, computer-optimized design techniques, and substantial improvement in cooling methods. Improved cooling was achieved in TEFC units by increasing the amount of frame finning: T-frame finning is about 50 percent more than that of U-frame on small integral motors and about 100 percent more on large sizes (Fig. 8). This gain in finning represented a marked advance in casting technology. (Both vintages of motor have frames cast from gray iron.)

A special form of TEFC motor has replaced the open lint-free textile motor discussed earlier. In it, particular attention is given to the design of the air flow passages to minimize lint pick-up by such means as eliminating rough protrusions and providing smooth surfaces.

The Motor of 1980

The progressive motor size reductions from 1940 to the present are illustrated in Fig. 9, along with a projected 1980 size/rating relationship. The projected gain from 1960 to 1980 is about the same order of magnitude as that from 1950 to 1960. I think it will be achieved by going from Class-B insulation (130 degrees C hot-spot temperature) to Class-F (155 degrees C hot-spot temperature) as standard for both dripproof and TEFC motors.

For dripproof motors, I envision a basic structure similar to our present T-frame motors except with air inlet openings in the vertical face of the end brackets instead of in the lower part of the axial portion of the brackets. This arrangement provides more inlet area and, more important, improved disposition of the area because air is fed in more uniformly around the entire end-bracket periphery. The 1.15 service factor on dripproof motors may be changed to 1.0 for standard machines, consistent with world standards. We have already successfully designed, built, and sold motors with these features and with a size/rating relationship per the 1980 curve in Fig. 9.

For TEFC motors, I envision increased frame finning as the means of dissipating the heat. Such finning is already in use, as shown by the one point in Fig. 8 above the T-frame curve for the 440 frame diameter. We have four 440-diameter TEFC frame lengths (444, 445, 447, 449) in our T-line; three of them have finning shown by the point on the curve, and one has finning shown by that point high above the curve. All four castings are production items, but few foundries have the technological capability to make the one extra heavily finned gray-iron casting as a regular production item at a practical cost. By 1980, however, I believe castings with this degree of finning will be economically feasible from a variety of sources. In smaller frame sizes, some

9—Physical size of integral-horsepower motors has been reduced through the years by continuing technical progress, and the reduction can be expected to continue. The ordinate of this graph is proportional to the motor dimensional quantity *diameter*^{3} × *length*. (*D* is NEMA shaft height, and *F* + *BA* is NEMA length from frame centerline to pulley shoulder on shaft.) The lines of slope equal to 1 were drawn to show that the slopes of all four motor curves closely approximate unity, thus indicating that *diameter*^{3} × *length* is an appropriate form for plotting motor rating. The curves are for standard 1800-r/min open dripproof motors.

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manufacturers are now producing aluminum TEFC frames with finning at even higher levels. Depending on the acceptance of these aluminum frames in some of the chemical industries, they may be the answer for 1980 TEFC motors in smaller integral sizes.

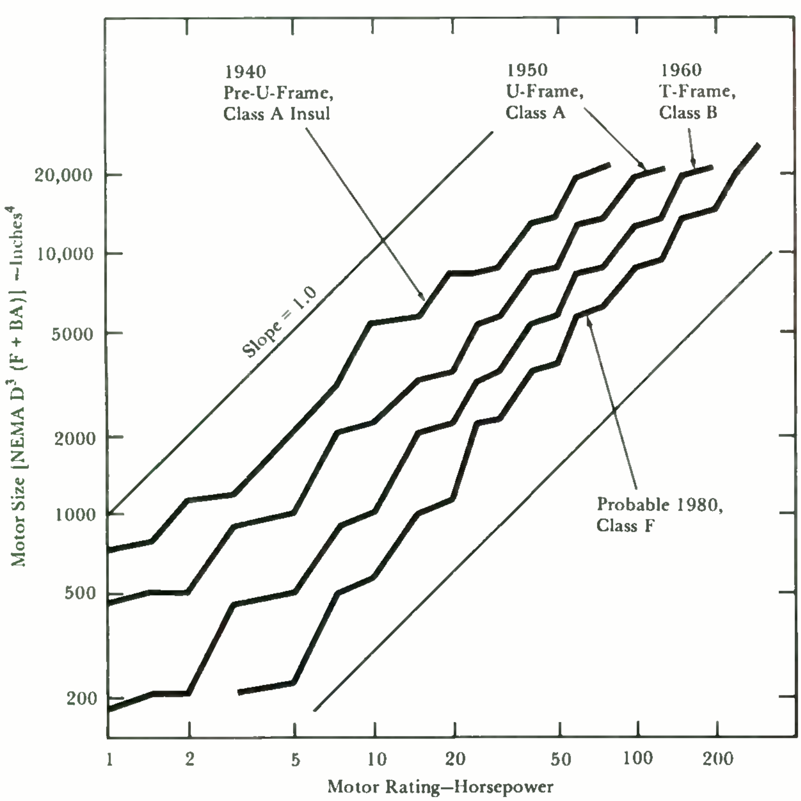
We can also expect improved lamination steel by 1980, a steel that can carry the necessary higher flux with no increase in iron ampere-turns.

I indicate 1980 for the time of the next motor size reduction, about a 20-year gap rather than the 10-year span between U-frame and T-frame lines, for several definite reasons. (The reasons reflect my personal opinion only, however, and obviously are not supported by the motor industry as an entity.)

First, the switch from Class-B insulation to Class-F as standard will require time for acceptance by motor users. Remember, Class-A insulation remained the standard for many years while Class-B was available for special motors. During those years, users came to recognize Class-B insulation first as a "necessary evil" for a few severe applications, then as a "just-as-good" alternative, and finally as a distinctly superior insulation system. These steps in user acceptance lagged somewhat behind the corresponding development stages of Class-B insulation. Today, Class-F insulation is relatively new. Modern Class-F systems utilize components made from new synthetics that not only have the high dielectric strength, mechanical ruggedness, and moisture resistance of Class-B systems but also the necessary higher thermal endurance. From a technical and reliability standpoint, Class-F is already in the "distinctly superior" stage, but it will take time for users to recognize that fact and accept it as well as to accustom themselves to the higher Class-F operating temperatures.

Second, lack of interchangeability is a problem for large users of motors each time a size reduction occurs. For that reason, acceptance of change was slow in some instances in both the U-frame and T-frame rerate programs; I believe it will take more time and more economic pressure before the motor industry moves to smaller frame sizes again, but the move will come.

Third, motor standardization is now picking up in international bodies. IEC (International Electrotechnical Commission, roughly an international counterpart to NEMA) has assigned committees to look into logical series of electric motor dimensions (which set the physical sizes) and ratings, but not a marriage between the two. It appears this IEC work will be complete by approximately 1980. United States standards must reflect, or at least recognize and be influenced by, the international standardization work; thus, I think it would be imprudent for the motor industry in the United States to embark on a size reduction program before 1980.



Conclusion

This brief summary has noted the high spots of induction motor history, concentrating largely on standard motors. From the standard motors, countless varieties of special motors have evolved, and, in many cases, the special motors pioneered concepts, components, or entire constructions that in turn appeared in later versions of standard motors.

REFERENCES:

[1] R. F. Woll, "AC Motor Rerate—A New Industry Standard," *Westinghouse ENGINEER*, Nov. 1965, pp. 175-81.

[2] R. F. Woll, "AC Motor Rerate—New Motors Are Both Smaller and Better," *Westinghouse ENGINEER*, Jan. 1966, pp. 16-9.

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The Landside/Airside configuration of the new Tampa International Airport consists of a central building encircled by four (eventually six) satellite buildings. Each Airside building is connected to the Landside building by a 1000-foot elevated transit leg with two vehicles shuttling on separate roadways. The unattended vehicles accommodate 100 passengers in air-conditioned comfort.

Airport Passenger Transport System Takes the Trudgery Out of Flying

An electronically controlled automatic passenger transfer system greatly reduces the amount of walking required at the new Tampa International Airport. It includes eight lightweight shuttle cars linking the large central "Landside" terminal building to four satellite "Airside" buildings designed to accommodate even the biggest jumbo jets.

The Landside building provides for parking, baggage handling, ticketing, and concessions. Airside functions—gate check-in, passenger holding, and apron operations—are grouped in the surrounding satellite buildings. The walk from car to plane normally is less than 700 feet, including a stop at the ticket counter; a plane-to-plane trip normally involves even less walking. Passengers and greeters are carried comfortably by elevators, moving stairways, and the shuttle cars.

The system was designed by Westinghouse as an adaptation of its Transit Expressway. Elevated transit legs about 1000 feet long connect the Landside building with each Airside building. There are two roadways per leg, each with a single vehicle for a total of eight in service to the four initial Airside buildings. (Four additional cars will serve two future Airside buildings.)

The cars comfortably accommodate 100 passengers, though they can handle as many as 125. They reach a peak speed of 30 miles per hour in their 40-second run between buildings. With station dwell time set at 30 seconds, cars are available every 70 seconds at any loading point. The two cars on a leg can move 840 passengers in one direction every 10 minutes. In that time, the four legs together can handle the passengers and expected greeters for eight fully loaded jumbo jets.

Normally the cars are slowed and stopped at stations by friction brakes activated by compressed air. However, if a car's speed at any point indicates that the brakes are not bringing it to a safe stop, a signal is given to a conventional railroad failsafe relay that releases a backup friction brake activated by a spring mechanism. This backup system, although necessary as a precaution, will most likely never be brought into play because a special-purpose subminicomputer on each car sees that the exact amount of braking effort is applied to stop the car within a few inches of the desired spot. The computer recalculates the required deceleration rate every six inches.

Propulsion is provided by two 100-horsepower dc series-wound motors, one driving each axle through a standard truck-type differential gear. A full-wave thyristor power supply converts three-phase ac power picked off the power rails for the motors; it provides a continuously adjustable dc voltage to assure that the motors respond smoothly to the acceleration commands of the automatic control equipment.

Each car travels on pneumatic tires running on concrete surfaces. An I-beam stringer midway between the running surfaces forms a guide, to which the car is locked by four guide wheels.

Vehicles on each leg are controlled by a system of wayside and car-carried equipment linked by two-way radio, which uses a car-carried antenna and a parallel-wire antenna running the length of each roadway. In addition, a phase-reversing signal from a transposed-wire antenna on the edge of the last few hundred feet of roadway in each direction provides precise position information to the car-carried "program stop" computer. The wayside equipment's logic is hard-wired and employs digital integrated circuits.

Generator Size and Weight Reduced by Spray Cooling

Spray-oil cooling, originally developed for aircraft electrical generators, has now been applied to tank generators to greatly reduce their size and weight. The generators were supplied by the Westinghouse Aerospace Electrical Division to General Motors Corporation, prime contractor for the XM 803 tank development program.

Oil ejected through calibrated spray nozzles at each end of the generator's rotor produces a spray that fills the generator cavity to cool all the parts evenly

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and more efficiently than other methods do, making possible substantial reduction in the size and weight of windings and other parts.* The generator is rated at 650 amperes and weighs 55 pounds. Generators developed for the predecessor tank program, before the advent of the oil-spray cooling technique, were rated at 700 amperes but weighed 155 pounds.

*J. K. Taulbee, "Integrated-Drive Generator for Aircraft Accelerates Trend Toward Less Weight and Longer Life," *Westinghouse ENGINEER*, Jan. 1971, pp. 15-19.

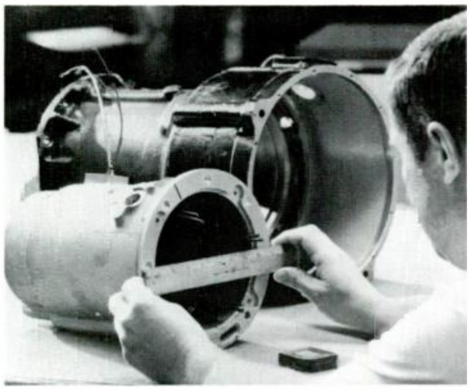
Reverse-Osmosis System for Home Purifies Tap Water

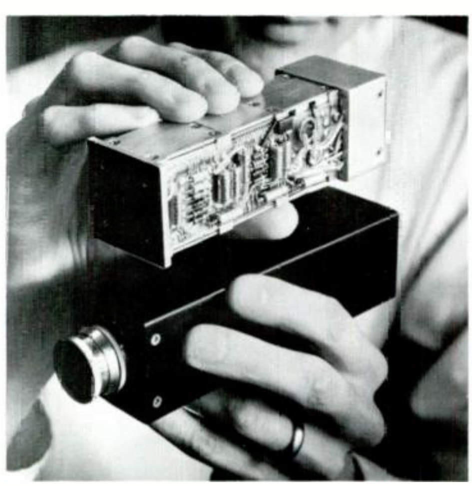
Tap water supplied by some municipalities, though safe to drink, is discolored, bad tasting, or excessively hard—or all three. Use of bottled drinking water is one solution to the problem, but it requires a relatively large space and depends on regular deliveries. To provide a more convenient solution, the Westinghouse Research Laboratories and the Portable Products Division have developed a compact purification system, based on reverse osmosis, that provides from three to five gallons of drinking water a day. The unit is portable and is normally connected to a sink faucet through a special diverter valve that allows tap water to bypass the unit when untreated water is wanted, as for washing.

The system employs a semipermeable membrane material similar to that used in the larger industrial and utility reverse-osmosis systems. (See *Reverse Osmosis: A New Tool for Water Purification,* p. 108.)

In operation, the sink faucet is left open and tap water flows through the diverter valve, through a plastic tube, and into the membrane array. There are 14 membrane sheets, stacked in layers with support plates and separator frames. Some of the feedwater is forced through the two membrane sheets located on either side of the first-stage separator frame; it emerges as purified product water and traverses along cloth layers to a collection manifold. The remaining feedwater is led through successive stages and finally to a drain line where it is joined by overflow from the storage reservoir and flows through a drain tube back to the sink.

Product water passes through an activated-charcoal filter cartridge and then into a 1.5-gallon storage reservoir. About five gallons of tap water are used to provide each gallon of purified water.





Top—Size of the housing of the new generator, on the left, compared with that of its predecessor dramatizes the striking size reduction made possible by advances in generator cooling. The rotor contains small oil spray ports that create a fine spray of oil in the generator cavity to cool stator windings and other parts evenly and effectively.

Center—Reverse-osmosis system for the home purifies tap water for drinking and for such other uses as cooking and coffee-making.

Bottom—Electronic circuitry and case of the subminiature television camera. The unit weighs 9 ounces and is 1½ inches square by 5 inches long (without the lens).

Subminiature TV Camera

Although small television cameras have been built, designers have not fully utilized the expanding integrated-circuit technology to achieve the size and reliability advantages inherent in that technology. Now, however, the latest advances in image-sensor and packaging areas have been mated in a subminiature television camera for testing as a feasibility prototype. It was developed by the Westinghouse Aerospace and Electronic Systems Division.

Probably the smallest television camera ever built, it weighs nine ounces and is 1½ inches square by 5 inches long. Its half-inch-diameter vidicon image tube is space qualified. The camera's circuitry is virtually immune to the effects of vibration because it is made up of inherently rugged hybrid integrated-circuit units.

Performance of the diminutive camera equals or exceeds that of conventional cameras. In addition, it has a switchable synchronization format (allowing use of American or European standards), fully

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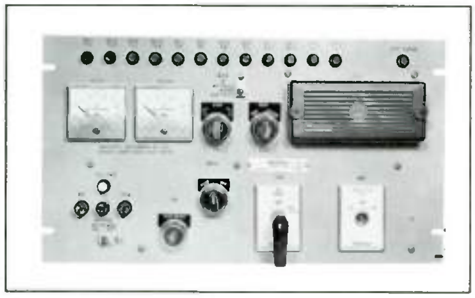
automatic light control capability, and an all-digital sweep failure detection mechanism. Beam focus is electrostatic and beam deflection magnetic. Input power is 6.0 watts at 12 ± 1 volts dc, and maximum resolution is 450 lines. Signal-to-noise ratio at 1 footcandle faceplate illumination is 40 dB.

The camera has six major circuits: preamplifier, postamplifier, sweep, sweep failure protection, synchronization, and input protection. Each is a separate hybrid integrated circuit that contains its own voltage regulator. Although the camera's own image tube is a half-inch vidicon unit, its other electronic parts could be used with a 1-inch electron gun such as those of standard low-light-level SEC or EBS tubes.

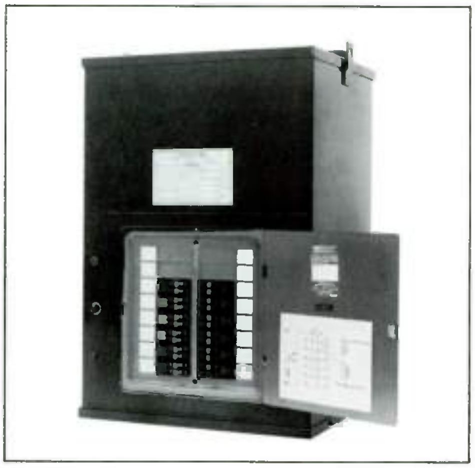
Products for Industry

Programmable translation system, the WLT-30, expands the Pulse-O-Matic magnetic tape recording system supplied for such utility uses as load studies, demand billing, and environmental monitoring. It consists of one or more tape readers, a teleprinter, a magnetic tape drive, and a data processor that enables it to perform functions not possible with other translators. Among them is a validity check of data from the field recorder tapes and selection of the peak demand interval for each data channel. Also, the data processor provides the necessary buffering to permit use of a synchronous magnetic tape drive with "read-after-write" electronics, which assures production of computer tapes free from parity errors. *Westinghouse Meter Division, Box 9533, Raleigh, North Carolina 27603.*

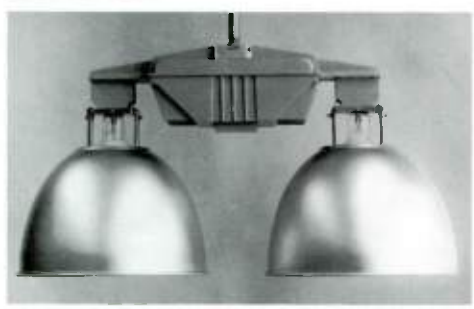
Functional testing unit (type FTU) provides a simple, economical, and rapid way to prove the reliability and performance of relay components and circuitry in any solid-state pilot relaying system. With it, electric-utility operating personnel can simulate internal and external protected line fault conditions, check the fault detectors, check decision logic, check output circuitry, and check directional comparison system channels from one location. *Westinghouse Relay-Instrument Division, 95 Orange Street, Newark, New Jersey 07101.*



Functional Testing Unit



Mini-Power Center



Flexoliner Mercury Luminaire

Mini-Power Center combines a distribution transformer, primary breaker, secondary snap-in breakers, and prewired panelboard into a single unit to save space, installation time, and material costs. Standard models are made for surface mounting to walls, columns, and panels. The power center handles up to 24 feeder circuits of 120 volts or 12 feeder circuits of 240 volts, and it is available in 3-, 5-, 7½-, 10-, 15-, and 25-kVA ratings. Its "Green Line" potted transformer accepts 480 volts on its primary side with a secondary output of 120/240 volts. *Westinghouse Specialty Transformer Division, Greenville, Pennsylvania 16125.*

Flexoliner mercury luminaire for industrial applications has a "Quickie" hanger for simple installation: it threads onto the ¾-inch conduit feed and locks with a setscrew. The prewired cast-aluminum ballast housing slides onto the hanger and locks in place, and the aluminum reflector then slides onto the ballast housing. The luminaire is available in single or tandem arrangements for all common wattages and voltages. *Westinghouse Outdoor Lighting Department, 1216 W. 58th Street, Box 5817, Cleveland, Ohio 44101.*

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About the Authors

Robert P. Taber is program manager in Westinghouse Special Systems for the U.S. Bureau of Mines rescue and survival system. His responsibility is application of modern technology, much of it developed for military and space projects, to the problem of keeping coal miners alive after a fire or explosion and then rescuing them.

Taber graduated from Carnegie Institute of Technology in 1947 with a BSME degree, and he later earned an MME at the University of Delaware. He joined Westinghouse on the graduate student training program and worked first as a design engineer in the Meter Division. In 1951, he transferred to the Aviation Gas Turbine Division, starting as a design engineer but soon becoming Section Engineer for engineering publications.

Taber went on to the Marine Division in 1957 to do systems engineering and to correlate consultants' efforts in the Polaris missile launcher program. He was made Manager, Systems Engineering, in 1963, responsible for the management of design, manufacturing, and contractual functions of three operating divisions toward production of the Polaris launching and handling systems and supporting services.

In 1966, Taber moved to the Underseas Division, serving first as Engineering Manager, Deep Submergence Systems Department, and then as Program Manager. He was made Manager of West Coast Operations for the Ocean Research and Engineering Center in 1968, and he was appointed to his present position last year.

Richard C. Banta graduated from Bucknell University in 1961 with a BSEE degree, and he then joined the Link Division of General Precision to work as a development engineer in flight simulation. In 1963, he joined the Westinghouse Aerospace Division, where his responsibilities consisted mainly of engineering development of image-sensing and optical subsystems for military systems.

Banta transferred to the System Operations Division (now Special Systems) in 1966 and contributed to the development and analysis of military communication, surveillance, and target-acquisition systems. When the coal-mine rescue program was originated, he became a member of the systems engineering group and was the principal investigator for study of mine explosions. Along the way, he has taken graduate courses at Johns Hopkins University and the University of Maryland.

James B. Wright graduated from the University of California in 1951 with a BSEE degree. He joined Westinghouse on the graduate student program, and in 1952 he became a sales engineer at the San Francisco office. In 1965 he went to the Heat Transfer Division, where he was made Sales Manager of Multistage Flash Evaporator Desalting Systems. He assumed his current position in 1970 as Reverse-Osmosis Project Manager.

Wright has been involved in such water purification projects as the Key West ocean-water desalting plant, the country's largest such facility at 2.62 million gallons per day. He has also helped in the development of a 5-million gallon per day plant for treatment of acid mine drainage in Pennsylvania.

Dwayne F. Rife graduated from the University of Utah with a BSEE degree in 1960. He joined Westinghouse on the graduate student training program and went to the Aerospace Electrical Division. He worked first as a sales engineer, responsible for the sale and administration of research and development programs.

In 1969, Rife was appointed Senior Market Planner with responsibility for market planning and product planning. In that capacity, he initiated the product planning studies that lead to the ACES concept described in this issue. He also found time to attend Bowling Green State University, where he earned an MBA degree in 1970.

Rife transferred to the Operating Cost Laboratory as a staff assistant early this year. His responsibilities there include conducting operating and product-cost studies with Westinghouse divisions and developing cost-improvement techniques.

Manvel A. Geyer is technical director for the ACES (Automatically Controlled Electrical System) development described in this issue. Previous responsibilities include major roles in development of the inverters for the Apollo command module and the L-1011 aircraft.

Dr. Geyer graduated from Ohio Northern University in 1958 with a BS degree in electrical engineering. After teaching two years there, he joined the Westinghouse Aerospace Electrical Division as an analytical engineer. He was assigned responsibility for creating a hybrid digital/analog computer, which was used for simulating solid-state inverters. Dr. Geyer also played a major role in analytical and simulation work for the Apollo inverter, for many aircraft electrical systems, and for a variable-speed constant-frequency power system. He earned an MS degree in electrical engineering from the University of Pittsburgh during that period.

Dr. Geyer took a leave of absence in 1965 to attend Ohio State University full time, earning his PhD in electrical engineering in 1969. He returned to the Aerospace Electrical Division as a Fellow Engineer in Power Conversion Systems, where he contributed to development of an asynchronous modulated-carrier inverter. He moved to the Control Systems section in 1969 to work on the ACES development.

R. F. Woll has had primary design responsibility for medium ac motor lines developed by Westinghouse over the past 25 years. He earned his BS degree in electrical engineering at the University of Pittsburgh in 1937 and joined the former Motor Division, then in East Pittsburgh, as a tester. He became a motor designer in 1939, and he has been concerned primarily with design and development of ac motors ever since.

Woll moved to Buffalo when the Motor and Gearing Division was established there. He is now a Fellow Design Engineer in Research and Development Engineering, Medium AC Motor and Gearing Division. A recent honor was his election as an IEEE Fellow for his "contributions to the design and understanding of ac machines."

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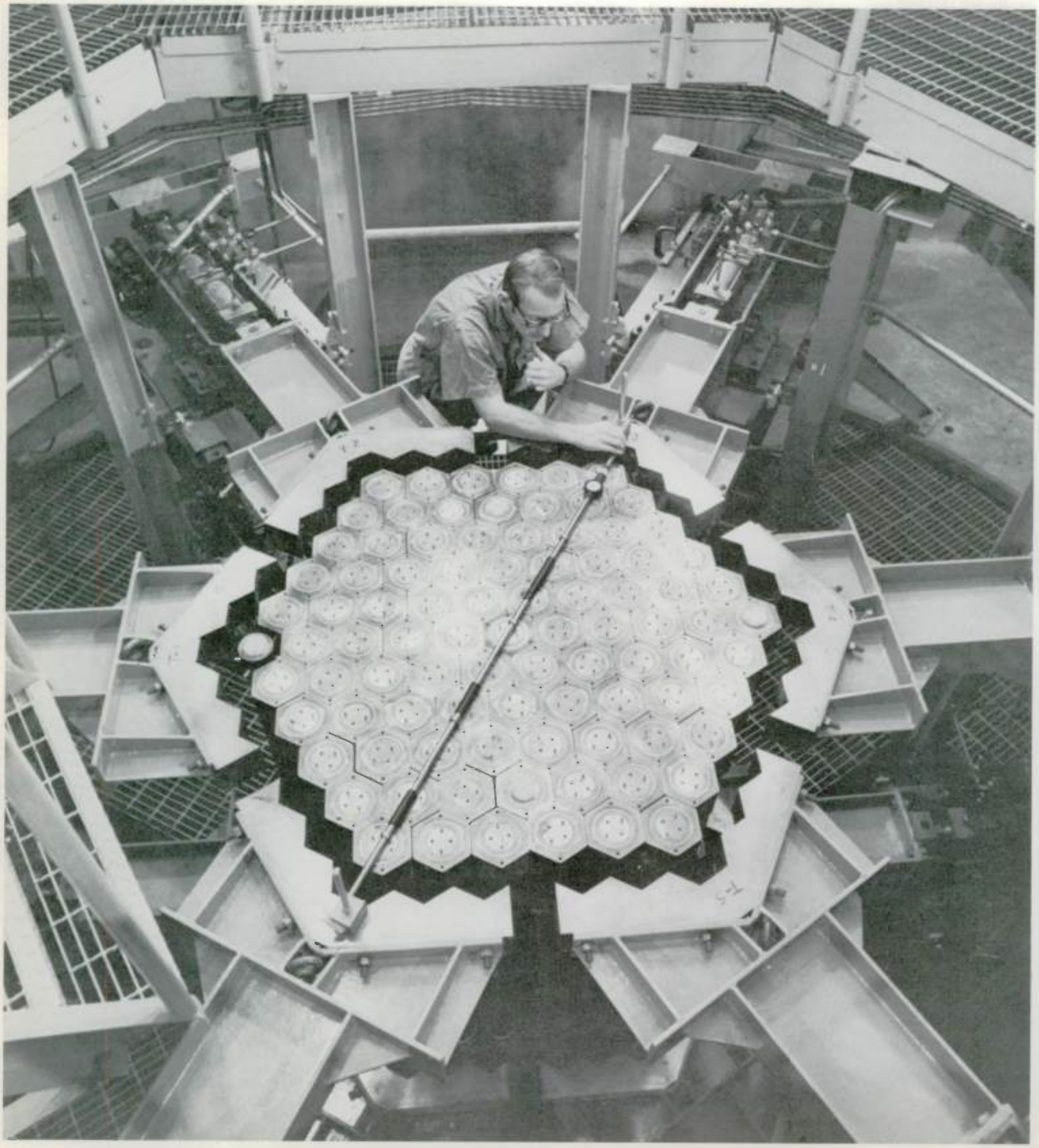

Simulated core mock-up for Fast Flux Test Facility.
(Information on contents page.)

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