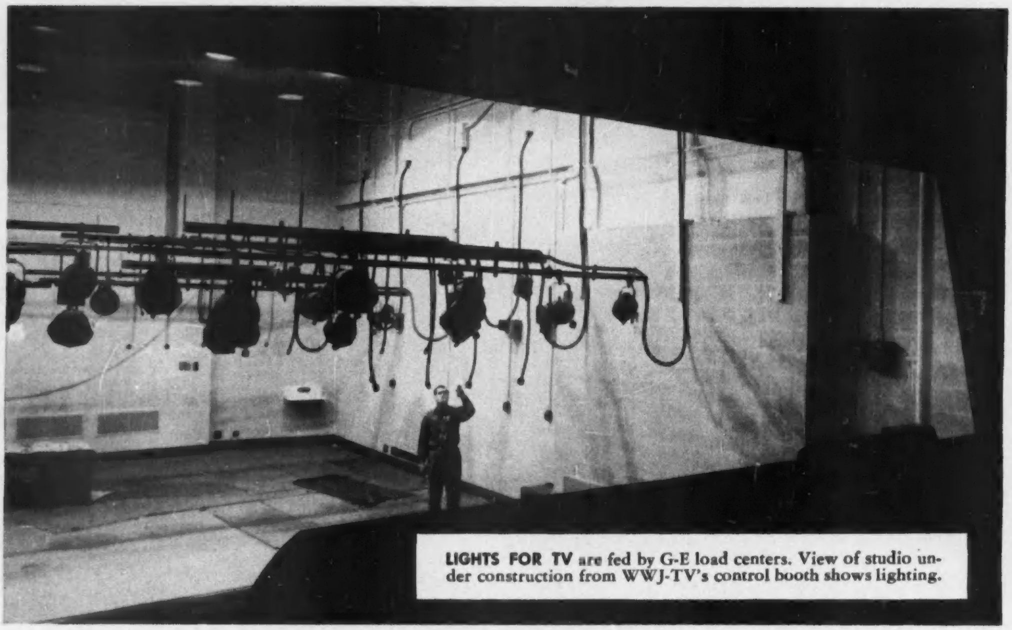
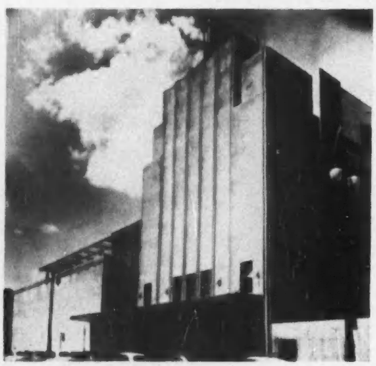
GENERAL ELECTRIC Review

NOVEMBER 1952

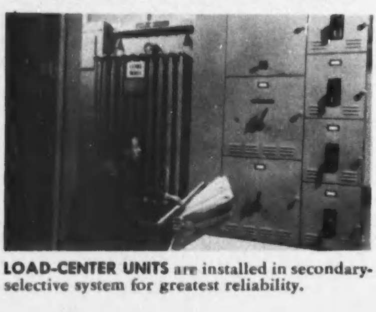


LIGHTS FOR TV are fed by G-E load centers. View of studio under construction from WWJ-TV's control booth shows lighting.

Where continuous power rates first!



NEW BUILDING houses WWJ-TV studios. G-E load-center system furnishes all studio power.



LOAD-CENTER UNITS are installed in secondary-selective system for greatest reliability.

Detroit's new TV studios rely on G-E load-center secondary-selective system.

At WWJ-TV—Detroit's pioneer TV station and affiliate of WWJ, the world's first commercial radio station—a dependable source of continuous power demanded top consideration in planning the new television studios.

For example, WWJ-TV needs power for lighting and amplifying . . . for monitor panels and relaying equipment . . . for station auxiliaries such as fans and blowers. To assure power continuity for these requirements, Giffels & Vallet, Inc., L. Rosetti, associated engineers and architects, and Jack A. Frost, electrical contractor, installed a G-E load-center secondary-selective system consisting of two 500-kva unit substations.

With load-center distribution, the station gains in other ways, too. A G-E engineered load-center power system maintains consistent voltage for full operating efficiency, reduces cable costs, and, because it's flexible, permits economical expansion in the future. Grounded, metal-enclosed load-center units assure maximum protection for studio personnel.

For full information on G-E engineered load-center power systems, call your local G-E sales representative, or write for GEA-3592, General Electric Company, Schenectady 5, N. Y.

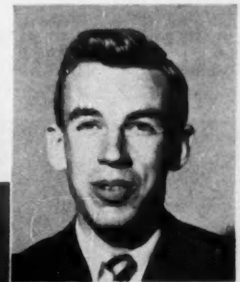
321-89

GENERAL ELECTRIC

MY QUESTION TO THE G-E STUDENT INFORMATION PANEL:

"What is General Electric's policy on employment in light of the draft?"

. . . John C. Bennett, University of Rochester, 1953



The answers to John Bennett's question - - excerpts taken from the panel discussion - - are given below.

R. J. CANNING, *Business Training Department* . . . Basically, the Company is interviewing and considering college students for employment without regard to their draft status. We're not passing over men because they are eligible for the draft—we're hiring them if they have the qualifications we want in our employees. We are looking at the area of employment on a long-range basis, and we think we are going to carry a perpetual inventory of men in the armed forces for a considerable period of time. It's true we lose some men, but we get many back, and with this in mind our policy is based on personal qualifications, not on draft eligibility.

J. L. MICHAELSON, *General Engineering Laboratory* . . . We are experiencing a growing appreciation of the importance of an adequate supply of well-trained professional people to this country's immediate and future welfare. Although this situation creates excellent opportunities for you students for future employment, the draft may leave you plagued by uncertainty for the present. But, remember this, we are not only considering college people for employment entirely for the year 1952. We are also thinking ahead to the years '54, '55, and '56, and if we find a good man now, knowing he is going into military service, we will still make long-range employment plans for him. We still would like to have him come with us after he has completed his military service.

M. M. BORING, *Engineering Services Division* . . . Whether or not you are called into military service you can reasonably expect to follow your profession for approximately 30 or 40 years. Your solution to the many problems, such as this one, which arise during your entire productive period, will be a lifetime undertaking. A period spent serving your country in a military way will represent a relatively small part of your total professional life. The way you handle a problem such as this, and the information you get to help in its solution, will determine to a large extent your ability to handle future problems.

Now, where does General Electric stand in regard to this draft situation? This is our policy. Regardless of military status, we desire to interview all students who are interested in our Company. And, irrespective of military status, we will make employment offers to all who have the qualifications we are looking for, and whom we would like to have become members of the General Electric family. If any of these people are called into service before starting work with us, business conditions permitting, our offers will be waiting for them when they return. Those with us before being called into service will maintain continuity, and, barring unforeseen circumstances, will be assured of employment upon return.

Following World War II we did not have to go back on a single promise. When the present world situation is concluded we hope our record will remain the same.

Do you have a question—or seek further information? If so, write to College Editor, Dept. 221-6, General Electric Co., Schenectady 5, N. Y.

GENERAL ELECTRIC

G-E HEAT PUMP Brings All-Electric Heating and Cooling to More and More Homes

NEW ORLEANS, LA. Model YR-50 Heat Pump System installed in basement heats and cools this large, two-story home.

TOLEDO, OHIO. Model YR-30 Heat Pump System handles this ranch-type home.

HOUSTON, TEXAS. G.E.'s no-water feature is especially liked in water-scarce areas. Unit accessible at rear of this home.

SARASOTA, FLA. Heat Pump is tucked away in corner of garage in this basementless home.

UNDER SOME CONDITIONS, supplementary heating is needed. Paul O'Neill, G-E Heat Pump Department, shows Harold Campbell, G-E Distribution Engineer, how this is influenced by heat loss of individual home, outdoor temperature, and design capacity of unit.

General Electric has moved the exciting new G-E Heat Pump out of the laboratory into the American home for the first time on a commercial basis. Markets have been carefully pin-pointed, principally in the South, Southwest, and Pacific Coast.

It means a wonderful new life to hundreds of American families, for they get clean, balanced heating in cold weather *without burning fuel*... and pleasant cooling and dehumidification in hot weather *without using a drop of water.*

The public's interest in the G-E Heat Pump has been tremendous, thanks to its unusual benefits: no fuel to burn or store ...ideal comfort all year...quiet, clean operation. No need for porches, fireplaces, flues, chimneys, windows that open.

The growing demand for air conditioning is paving the way for even more dramatic success. Utilities are finding the Heat Pump offers an opportunity to add year-round power consumption and smooth out annual load requirements. It is influencing home design. The dream of ideal home comfort is a reality. General Electric Co., Air Conditioning Division, Sec. GER-8, Bloomfield, N. J.

GENERAL ELECTRIC

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GENERAL ELECTRIC Review

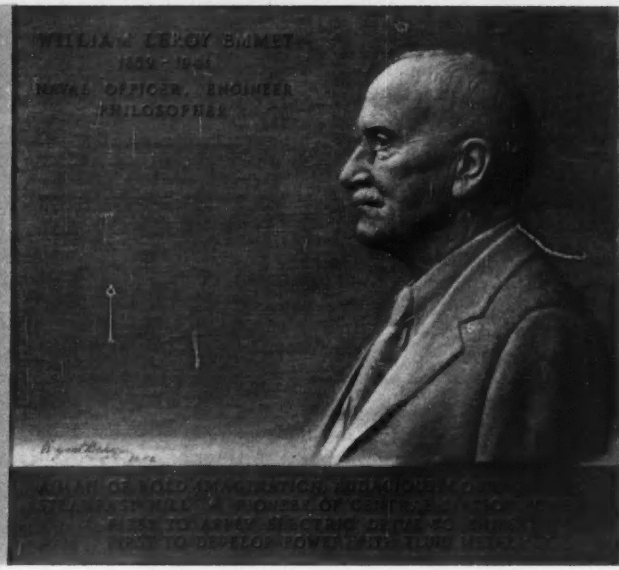
EVERETT S. LEE • EDITOR PAUL R. HEINMILLER • MANAGING EDITOR

COVER—This cloud of ice crystals was created at 27,000 feet over Schenectady by an airplane seeding the air with silver-iodide smoke. The circle is about five miles in diameter. The first complete and exclusive story of "Project Cirrus" and cloud seeding begins on page 8.

THE GENERAL ELECTRIC REVIEW IS ISSUED IN JANUARY, MARCH, MAY, JULY, SEPTEMBER, AND NOVEMBER, BY THE GENERAL ELECTRIC COMPANY, SCHENECTADY, NY, AND IS PRINTED IN THE U.S.A. BY THE MAQUA COMPANY. IT IS DISTRIBUTED TO SCIENTISTS AND ENGINEERS THROUGHOUT INDUSTRIAL, CONSULTING, EDUCATIONAL, PROFESSIONAL SOCIETY, AND GOVERNMENT GROUPS, BOTH DOMESTIC AND FOREIGN. . . . THE GENERAL ELECTRIC REVIEW IS COPYRIGHTED 1952 BY THE GENERAL ELECTRIC COMPANY, AND PERMISSION FOR REPRODUCTION IN ANY FORM MUST BE OBTAINED IN WRITING FROM THE PUBLISHER. . . . THE CONTENTS OF THE GENERAL ELECTRIC REVIEW ARE ANALYZED AND INDEXED BY THE INDUSTRIAL ARTS INDEX, THE ENGINEERING INDEX, AND SCIENCE ABSTRACTS. . . . SIX WEEKS' ADVANCE NOTICE, AND OLD ADDRESS AS WELL AS NEW, ARE NECESSARY FOR CHANGE OF ADDRESS. . . . ADDRESS ALL COMMUNICATIONS TO: EDITOR, GENERAL ELECTRIC REVIEW, SCHENECTADY 5, NEW YORK.

W. L. R. EMMET MEMORIAL

As an expression of esteem for William LeRoy Emmet, the Schenectady Professional Engineers' Society unveiled on The Green at General Electric Company, Schenectady, October 31, 1952, this bronze plaque commemorating the 50th anniversary of Mr. Emmet's Niagara generators. The plaque, 26 by 30 inches, was made by artist Bryant Baker. It is mounted on a 6-ton bluestone boulder. Limestone blocks from the old Erie Canal form the base.



EXACTLY 50 YEARS AGO, on October 31, 1902, the first generator in Adams Station No. 2 at Niagara Falls went on the line. Ten sister machines—each rated 5000 hp, 250 rpm, two phase, 25 cycles, 2200 volts—followed rapidly, the last going into service on March 16, 1904. Ever since, when water was available, these generators have continued to deliver power 24 hours a day. And they are still doing so.

After 20 years of continuous operation, one of them required repairs because of accidental mechanical damage. And since then, five have been rewound. Aside from this, all 11 machines are the same as when they left the factory half a century ago.

The Niagara Falls Power Company gave the Adams Station No. 2 contract to General Electric ". . . for the reason that they had great confidence in W. L. R. Emmet, who had planned and would direct the work."

Mr. Emmet described the occasion in these words—"I can hardly give an idea of the triumph which I felt when this matter was settled. I was athirst for something big to do, and this was the biggest thing in the electrical world. Every detail of what I intended to do was in my mind, as if the plant had been running for months. I had planned the construction of the generators and had them studied and calculated over and over again."

The generators at Niagara are but one of many monuments to the genius of William LeRoy Emmet. He began installing trolleys for Frank Sprague in 1888. It was said in later years one could tell any system he had worked on, because there were hardly two parts alike. He changed or rebuilt factory parts without the knowledge of the designers but to the great advantage of the users. In 1891, he became Chicago District Engineer for Edison General Electric. Three years later he came to Schenectady where his great talents as inventor, organizer, and promoter of radically new engineering projects unfolded rapidly.

After the Niagara project, he developed the first large steam turbines—the 5000-kw vertical machines installed in Chicago in 1903. Together with Oscar Junggren, he developed the modern-type large multistage horizontal Curtis turbine, which is still the major source of central-station power. He proposed gap cooling and forged rotors for turbine generators and welded steel plate instead of castings for machine frames. He pioneered electric drive for ships of many types, and successfully applied his system of "proportionate thinking" to other developments.

The mercury-vapor process of power generation, known by his name, absorbed his energy during the last 20 years of his career. Immense technical difficulties were surmounted, and the knowledge so gained has provided a firm foundation for the use of other fluid metals.

Many honors came to Mr. Emmet. He was awarded the Edison Medal of the AIEE, and was elected an Honorary Member of the ASME. He was a member of the Naval Consulting Board and the National Academy of Sciences. His younger associates and many friends knew him affectionately as "Uncle Bill." Indeed, in the words of E. W. Rice, his long-time associate and friend, "W. L. R. Emmet was a man of bold imagination, audacious courage, and steadfast will." Ω

IES GOLD MEDAL AWARD

On the occasion of the opening session of the Illuminating Engineering Society's Annual National Technical Conference, held in Chicago, September 8, H. Herbert Magdsick (left) of the General Electric Co., Nela Park, Cleveland, was presented the IES Gold Medal for 1952. This medal—highest honor in the field of illumination—is awarded for meritorious achievement conspicuously furthering the profession, art, or knowledge of illuminating engineering.

TWENTY-FIFTH PRESIDENT of the Illuminating Engineering Society, Fellow since 1945, and member for more than two score years, H. Herbert Magdsick has rendered distinguished service to the Society in many capacities. And through his contributions, illuminating engineering has been advanced along many avenues.

When the gas-filled incandescent lamp became available in 1914, Mr. Magdsick designed pioneering floodlighting installations including the Woolworth Tower and the Statue of Liberty. Likewise, he established the new source as the dominant illuminant for streets.

In 1923 he conducted the first International Lighting Mission, extending firsthand study of American Lighting activities to European and South American representatives. Subsequently, he assisted in organizing lighting centers in Europe, of which the ELMA Bureau in London was one.

His numerous pioneer studies established basic requirements and contributed fundamentals of an adequate technology for a variety of applications of visible, infrared, and ultraviolet radiation.

Combining an analytical mind and a penetrating imagination—backed by extensive technical training and professional integrity—Mr. Magdsick's efforts have added materially to the foundations for lighting practice and progress.

Inevitably, his unselfish leadership and rare administrative ability are destined to leave indelible imprints upon men, as his technical contributions have left their influence upon materials and methods. His manifold contributions have permanently enriched the Society and the profession it represents. Ω

UNSEEN MATHEMATICS • Many said, "No mathematics in the new REVIEW—we can't understand it". But it is there just the same.

I was thrilled to read in the memorial to Mr. Emmet of the triumph in his heart when, as a young engineer, he said of his Niagara generators, "I had planned the construction of the generators and had them studied and calculated over and over again." Bill Emmet worked his mathematics overtime and it brought him a quality product.

Without mathematics throughout lamp development the vast illuminating systems for which Herbert Magdsick is honored would not have come into being.

In the Project Cirrus story (page 8), Dr. Langmuir returns again and again from his scientific observations to his mathematical calculations. Probability and correlation coefficients may be far away for some, but when Dr. Langmuir calculates the day's rainfall from seeding to be 1600 million tons or 320 billion gallons, he brings you a result in familiar terms.

In today's shortage of engineers let every engineer look to the schools in his locality to be sure that administrators and teachers and parents are alive to the need for mathematics, and that every capable student is studying mathematics. Thus at graduation time no one will be prevented from advancing into engineering training, or from taking semitechnical jobs, because of a deficiency in math. And the same applies to physics and chemistry.

Mathematics is too much unseen. It ought to be more in the news.

—EVERETT S. LEE, EDITOR

1 One morning in July, 1950, near Socorro, NM, these small cumulus clouds at 15,000 feet were the only ones to be seen. At 9:58 one of these clouds, located about 15 miles NW of Socorro, was seeded by making one pass through it at 2500 feet above the base with a spray-nozzle-type silver-iodide burner in operation. A few minutes after the seeding . . .

"Project Cirrus"—The Story of Cloud Seeding

- Here, for the first time, is the complete and exclusive story of man's successful attempt to modify and control the weather

- The results of Project Cirrus' five years of weather research will have a profound influence upon domestic and world economics

- Periodic cloud seeding seemed to produce a tendency to periodic rainfall that extended all over the U. S.

- Making it rain, modifying thunderstorms and hurricanes, and clearing ground fogs near airports are some of the vital possibilities

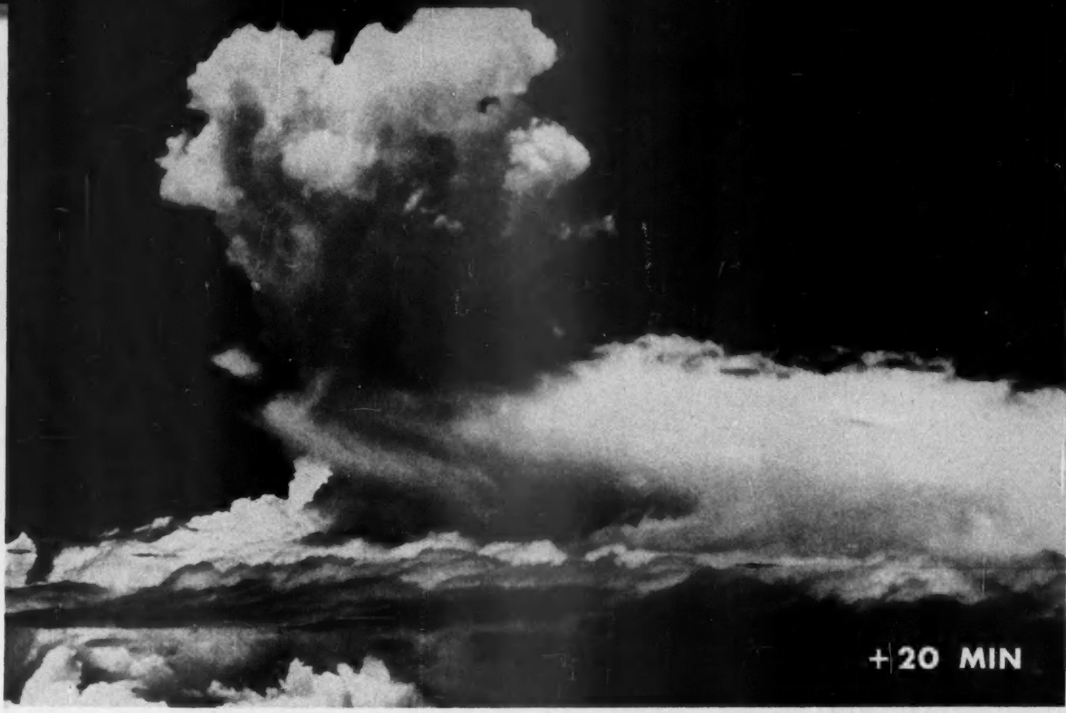
It began in 1940 with a study of the fundamental nature of filtration in gas masks.

This work was undertaken by Dr. Irving Langmuir and Dr. Vincent J. Schaefer (picture, page 10) of General Electric's Research Laboratory in Schenectady at the request of the Chemical Warfare Service.

Gas masks normally use charcoal to absorb poison gases, but even in World War I the possibility arose that the enemy might use toxic smokes that could not be absorbed by charcoal and thus would have to be removed by some other type of a filter.

The first step in attacking the problem was to make some smokes of the type for which the filters would be used. In doing so, the scientists studied the particles that composed the smokes and soon learned how to build a good filter. And, they acquired a great sum of detailed knowledge as to how to make smokes.

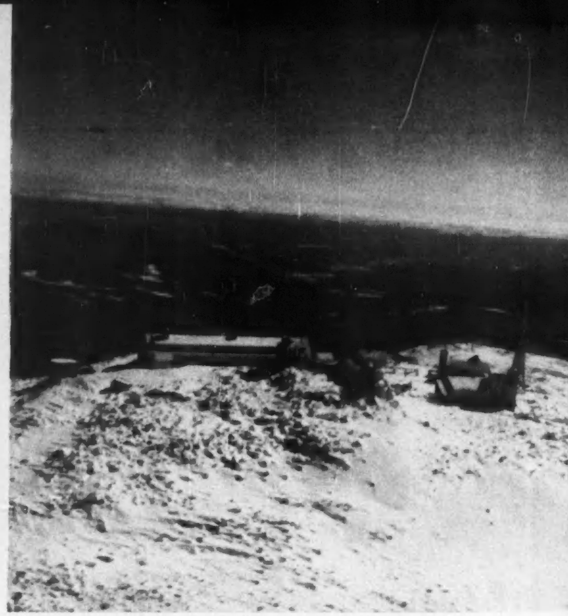
This work was done under a National Defense Research Council (NDRC) contract. As Langmuir and Schaefer neared the end of the work, they received a form letter in August, 1941, asking if anyone could think of a way to make a white screening smoke that could be used over large areas to cut down the hazard from enemy aircraft.



2 The cloud top soon changed from a hard white in appearance to a gray cirrus-like structure. In 20 minutes it had grown greatly in size. Operation of the silver-iodide burner in the seeding airplane is simple: a solution of silver iodide in acetone and sodium iodide is atomized in the nozzle, using a compressed inflammable gas such as hydrogen or butane

3 The cloud continued to grow and by 11:11 it had become a large thunderstorm. Rain fell. This picture was taken from an airplane at a distance of 80 miles. Similar results took place in New Mexico when clouds were seeded by silver-iodide generators on the ground (page 19; pictures, pages 22–23). Dry-ice seeding from aircraft has also modified clouds

SCIENTISTS VONNEGUT, LANGMUIR, AND SCHAEFER



MT. WASHINGTON OBSERVATORY IN NEW HAMPSHIRE

Langmuir and Schaefer wondered whether they couldn't do this by using the methods they had adopted for making smokes for testing filters. They decided to try.

Further work and experimentation showed that they could produce smoke and control the particle size on a big scale. Larger generators were built, tests were made, and the design was adopted by the Army and used successfully during the war.

Precipitation Static

Quite independently of this work, the Secretary of War in 1943 asked for research into the problems of precipitation static. It was believed that an invasion by Japan would come largely from air attacks through the Aleutian Islands, across Alaska, and south to this country.

Operating aircraft in the Aleutians was a murky business. One of the big problems was icing of the aircraft, but even more baffling was the complete loss of radio contact when the planes flew through snowstorms. The planes might become charged to a potential of 250,000 volts or more, producing corona discharges from all parts of the plane, and causing such electrical disturbances that radio sets were crippled. Pilots had difficulty in finding their bases and getting down through the bad weather. What could be done about it?

Langmuir and Schaefer were interested. They had no particular ideas on the subject except that it had to do with weather. In their opinion the best place to investigate something like that was at the well-equipped laboratory of the Mt. Washington Observatory on top of Mt. Washington in New Hampshire (picture, above).

Mt. Washington in winter has an average temperature of minus four or five degrees Fahrenheit, the wind averages about 60 mph, and most of the time clouds sweep over the summit. It seemed to offer the proper conditions for research of this kind.

So equipment was installed and Schaefer went there several times during the winter of 1943 to conduct experiments. But he discovered that anything exposed there during the winter immediately became covered with ice, because the air was full of supercooled water droplets. He and Langmuir became so interested in this that they hoped they would not have to continue a long study of precipitation static.

Aircraft Icing

It so happened that the Army Air Force was just as interested in problems of aircraft icing as in precipitation static. This fitted in so well with the new interest of Langmuir and Schaefer that in 1944 they started a study of aircraft icing.

Soon the scientists began to acquire a very satisfactory understanding of some features of cloud structure and the growth of cloud particles. They became absorbed in their new interest.

But, although they felt they had a fundamental theory for some of the factors that caused particles to grow in clouds, they didn't feel conditions were right for further study on Mt. Washington. It would be far better to study cloud particle growth in airplane flights.

This was late in 1946. They took up the question with the Army Air Force and the Signal Corps. They were led to believe that perhaps somebody might furnish aircraft for experimental purposes of this sort; it seemed that it would be desirable to know something about clouds from a standpoint of national defense. But they didn't get very far. They continued the Mt. Washington research on their own to a large extent, but they never did get tests in aircraft.

Nucleation

By this time they were deeply interested in their cloud study. One thing that struck them was that, if there are any snow crystals in a supercooled cloud, they must grow rapidly and should tend to fall out. They came to the conclusion that in winter, if there are supercooled stratus clouds from which no snow is falling, even though the temperatures in the clouds are below freezing, there must not be any appreciable number of effective snow nuclei.

Why was it that sometimes snow forms so easily, with apparently no lack of nuclei on which crystals can grow, and at other times there seem to be none? They concluded there must be something in the atmosphere that causes water droplets to change to ice only at certain times and under certain conditions. They decided to make some careful experiments in the laboratory in an attempt to duplicate those conditions.

Schaefer's Cold Box

While Langmuir was in California for a few months in 1946, Schaefer made what Langmuir has described as "some beautiful experiments." During the previous winter he had studied the behavior of droplets on cold surfaces to see how they supercooled or froze as the temperature dropped. He found that he could supercool water drops to as low as −20 C on surfaces coated with polystyrene and similar materials. He had realized however that such experiments were not simulating supercooled clouds and had sought a better method of experiment.

He decided to try a home freezing unit of the type used for food storage. He lined it with black velvet so that he could get a good view of what happened inside when he directed a beam of light into the box. He then breathed into the box, and the moisture condensed and formed fog particles that were just like ordinary cloud particles, although the temperature was about −23 C. No ice crystals formed. He tried many different substances dusted into the box to get ice crystals to form, but he seldom had much success. He got just enough to convince him that if he did get more, he could easily see them.

Finally, one July day when the temperature of the chamber was not low enough, he dropped a big piece of dry ice into it to lower the temperature. In an instant the air was full of ice crystals. The crystals persisted for a while after he removed the dry ice.

Following this discovery, Schaefer conducted a number of experiments. These showed that even a tiny grain of dry ice would transform the supercooled cloud in the cold box to ice crystals, and that many millions of crystals could be produced in this manner.

To find out if there was something peculiar to dry ice which produced this effect, he worked with other cold materials. For example, he showed that by dipping a common sewing needle into liquid air and then passing it momentarily through the supercooled cloud in the cold box (picture, right), similar spectacular effects occurred. This demonstrated that the presence of a sufficiently cold substance was all that was required to produce the effect. Using various techniques Schaefer determined, with considerable accuracy, that the critical temperature at which the supercooled cloud changed to ice crystals was −39 C ±0.5 degree.

Schaefer's discovery changed the whole situation. It meant, first, that it was not the dry ice or the needle as such that was responsible for the effect, but the temperature. Anything could be used having a temperature of −40 C or colder.

Vonnegut's Early Work

Meanwhile the stage had been set for another important contribution to this pioneering work in meteorology. Before Dr. Bernard Vonnegut (picture, page 10) became associated with the G-E Research Laboratory in the fall of 1945, he was employed at Massachusetts Institute of Technology where he worked on smokes for the government's Chemical Warfare Service. Later he became interested in the problem of airplane icing and also did some work on supercooling.

Vonnegut had been interested in the work being done by Langmuir and Schaefer and had kept in close touch with it. In the fall of 1946, Langmuir asked him if he would be interested in helping with the quantitative work being done on the number of ice crystals produced by dry ice. As a result, Vonnegut applied himself to this and other problems in the general study of nucleation.

Silver Iodide

It occurred to Vonnegut that some substance very similar to ice in its crystal structure might serve as the nucleus for the formation of ice crystals in the cold box. He went through all the known tables of crystal structure and, from more than a thousand compounds, selected three substances that he thought might have possibilities: lead iodide, antimony, and silver iodide.

He dropped samples of each of these three substances into Schaefer's cold

SCHAEFER MAKES SNOW IN A HOME FREEZER

box. The results were almost negligible, although he produced enough effect with the lead iodide to warrant further experiment. He and Schaefer tried iodoform and iodine and obtained ice crystals in small numbers with them, too, but nowhere near as many as with dry-ice seeding.

The problem intrigued Vonnegut. He decided to try a metal smoke instead of the powder. He introduced some silver smoke into the box by drawing an electric spark from a piece of silver. The result was a spectacular swarm of ice crystals.

Next, he decided to try silver iodide, but this time as a smoke, for the effect with silver did not persist. First he vaporized silver iodide and then he introduced into the cold box the smoke resulting from the rapid condensation of this vapor. It was a complete success. Further investigation showed that his earlier negative results with silver iodide were caused by impurities. Powdered silver iodide worked when it was reasonably pure. He also found that the reason for the successful use of iodide was again impurity—contamination with silver.

The problem then became one of finding out something about how silver iodide worked, and of finding methods of generating silver-iodide smoke of small particle size on a large scale. Calculations showed that so many nuclei could

"... I was thrilled to see long streamers of snow falling ..."

be produced with silver-iodide smoke that all the air of the United States could be nucleated at one time with a few pounds of silver iodide. Thus the air would contain one particle of silver iodide per cubic inch—far more than the number of ice nuclei occurring normally under natural conditions.

Early Seeding Calculations

Meanwhile Schaefer and Langmuir had continued their study of the effects of dry ice. In August of 1946 Langmuir made a theoretical study of the rate of growth of the nuclei produced by dropping pellets of dry ice through clouds of supercooled water. With a reasonable number of pellets dropped along a flight path into the top of a cloud, the limiting factor would not be the number of nuclei but the rate at which they could be distributed throughout the cloud.

He also showed that such a formation of ice and snow particles would raise the temperature of the cloud, and he calculated the amount of temperature change. Thus the air in the cloud would be caused to rise, increasing its upward velocity because of the seeding. The resulting turbulence would spread the ice nuclei throughout the cloud. He anticipated that it would only be necessary to seed a stratus cloud along lines one or two miles apart to give complete nucleation of the cloud within a period of 30 minutes or so.

First Man-made Snowstorm

Thus the stage was set for actual experiment with an airplane in real clouds. On November 13, 1946, a Fairchild airplane was rented at the Schenectady airport and Schaefer went aloft with pilot Curtis Talbot, Manager of G-E's Flight Test Division, in search of a suitable cloud. It was found over Pittsfield, Mass., about 50 miles east of Schenectady, at an altitude of 14,000 feet and a temperature of −20 C. What happened next is best described by this extract from Schaefer's laboratory notebook:

> Curt flew into the cloud and I started the dispenser in operation. I dropped about three pounds (of dry ice) and then swung around and headed south.
>
> About this time I looked toward the rear and was thrilled to see long streamers of snow falling from the base of the cloud through which we had just passed. I shouted to Curt to swing around and, as we did so, we passed through a mass of glistening snow crystals! . . . We made another run through a dense portion of the unseeded cloud, during which time I dispensed about three more pounds of crushed dry ice . . . This was done by opening the window and letting the suction of the passing air remove it. We then swung west of the cloud and observed draperies of snow which seemed to hang for 2–3000 feet below us and noted the cloud drying up rapidly, very similar to what we observe in the cold box in the laboratory . . . While still in the cloud, as we saw the glinting crystals all over, I turned to Curt and we shook hands as I said, "We did it!" Needless to say, we were quite excited.
>
> The rapidity with which the CO_2 dispensed from the window seemed to affect the cloud was amazing. It seemed as though it almost exploded, the effect was so widespread and rapid . . .
>
> When we arrived at the port, Dr. Langmuir rushed out, enthusiastically exclaiming over the remarkable view they had of it in the control tower of the G-E Lab. He said that in less than two minutes after we radioed that we were starting our run, long draperies appeared from the cloud vicinity.

This first seeding flight was of tremendous significance. Not only did it show that the laboratory experiments and calculations were justified, but it also contributed new material to the rapidly accumulating store of knowledge. For example, it suggested that the veil of snow that first appeared immediately below the cloud could not have been produced by snow falling from the cloud but rather was produced directly by the action of the dry-ice pellets falling into a layer of air below the cloud which was saturated with respect to ice, but not with respect to water.

Subsequent experiments proved that it was also frequently possible to seed a supercooled cloud by flying just below it and dropping dry ice. The thickness of the layer in which such seeding is possible is about 10 meters for each degree Centigrade below the freezing point at the cloud base. The ice crystals thus formed may be carried up into the cloud if the cloud is actively growing by convection.

Other Early Flights

Schaefer made two other seeding flights with a rented plane that month; the tests were made on isolated cumulus-type clouds. The whole of each cloud was changed into ice within five minutes, and snow began falling from the base of the cloud.

Photographs were taken from the ground every 10 seconds and were developed and projected as movies. They showed that with orographic clouds—clouds that form as moist air is forced to rise when it encounters a barrier such as a mountain range—the air moves into one part and leaves another part; in a matter of five minutes or so an entirely new mass of air is within the cloud. Thus it was found that experiments with small cumulus clouds are usually of little interest, for the effects last but a few minutes.

Another flight test was made on December 20, also using a rented plane. This time the sky was completely overcast, and by 9 o'clock in the morning the Weather Bureau in Albany reported that it expected snow by 7 o'clock that evening. At noon Schaefer dropped about 25 pounds of granulated dry ice in the lower part of the cloud at a rate of one to two pounds per mile about 1000 feet above the irregular and ragged base of the overcast, at altitudes ranging from 7000 to 8500 feet. A two-pound bottle of liquid carbon dioxide was also discharged into the cloud during this period.

Before and during the seeding flight a light drizzle of supercooled rain had been encountered that seemed to evaporate before it reached the ground. Flying back along the line of seeding, after seeding was completed, it was found that the drizzling rain had stopped and that it was snowing. But on reaching the point where the seeding had stopped, drizzle conditions were again encountered. Three more seeding runs were made along the same line.

The plane then descended to 4000 feet, where the visibility was better, and made a reconnoitering flight, checking the places where snow was falling. By this method and through reports received it was found that snow started to fall in many places in the region. At 2:15 pm it started snowing in Schenectady and at many other places within 100 miles. It snowed at the rate of about one inch per hour for eight hours, bringing the heaviest snowfall of the winter. While the seeding group did not assume it had caused this snowstorm, it did believe that, with weather conditions as they were, they could have started a general snowstorm two to four hours before it actually occurred, if they had been able to seed above the clouds during the early morning.

Project Cirrus Formed

This, then, was the situation in which the research workers found themselves by the end of 1946: Their work on precipitation static, then on aircraft icing, had developed through cloud studies into meteorological work of profound significance. But while their work on precipitation static and aircraft icing had been done under government contract, the work they were now doing on weather research was not. Their last contract had expired the end of June.

At this point Dr. C. G. Suits, Vice President and Director of Research of General Electric, reported some of the results of cloud seeding to Company officials. While it was clear that weather modification and experimental meteorology were remote from the research which had been the traditional interest of the laboratory and the Company, it was equally clear that these new results were possibly of very great significance to the nation. It was decided that the work should go forward.

Because the results might have such wide application to the country generally, and because much government assistance would be needed in the form of weather data, airplanes, and flight equipment, a government contract for the continuation of the work was to be sought. While the government agency that had sponsored the previous research was not interested in the new work, other government agencies were. Normal contacts with the Signal Corps, for example, had kept that organization in touch with the new research, and Col. D. N. Yates, chief of the Air Weather Service, had asked the Company to submit a bid covering this work in the latter part of September. A formal proposal covering cloud modification and cloud particle studies was submitted to the Evans Signal Laboratory at Belmar, NJ (a Signal Corps unit), on September 20. Meanwhile the weather studies were being conducted at General Electric expense, although General Electric anticipated no benefit resulting to the Company by the work from a meteorological standpoint.

The flight test of December 20 added a powerful stimulus to the Company's negotiations with the government. Although the General Electric press release covering it did not claim that the general snowstorm was caused by the seeding, the coincidence of the two events did cause some independent speculation over the possibility of cause and effect.

Company officials recognized that the possibility of liability for damage from cloud seeding experiments was a very worrisome hazard in this new form of cloud experimentation. There was great reluctance to incur risks of uncertain but potentially great magnitude that would be a threat to the share-owners' money.

It was considered particularly important for this reason that any seeding experiments be conducted under government sponsorship. No further seeding flights were made until such sponsorship was provided.

A contract was finally received from the Signal Corps covering "research study of cloud particles and cloud modifications" beginning February 28, 1947.

An important part of the contract was a subparagraph stating that "the entire flight program shall be conducted by the government, using exclusively government personnel and equipment, and shall be under the exclusive direction and control of such government personnel." The Research Laboratory immediately notified all those involved in the research "that it is essential that all of the G-E employees who are working on this project refrain from asserting any control or direction over the flight program. The G-E Research Laboratory responsibility is confined strictly to laboratory work and reports."

Although the contract was a Signal Corps contract, the project actually had joint sponsorship by the U. S. Army Signal Corps and the Office of Naval Research, with the close co-operation of the U. S. Air Force, which furnished airplanes and the necessary personnel.

The title of Project Cirrus was not applied immediately. It went into effect officially on August 25, 1947.

ORGANIZING PROJECT CIRRUS

The over-all direction of the project was centered in a Steering Committee, consisting of representatives of the three military branches co-operating in the project. Langmuir and Schaefer served as consultants. Activities of members of GE's Research Laboratory staff—known as the Research Group—were limited by the Steering Committee to laboratory work and analysis.

The first step of the Steering Committee was to form an Operations Group. It had both civilian and military personnel and was under the direction of an Operations Committee.

The initial personnel of the Operations Group consisted of six representatives from each of the three Services. Although the number of General Electric people remained fairly constant at six or seven, the government representatives varied widely in number. As a consequence, the total personnel of the project varied also, running as high as 41 persons at various times during peak activities. A total of 33 persons went on the Puerto Rico operation, and 37 went on the second trip to New Mexico.

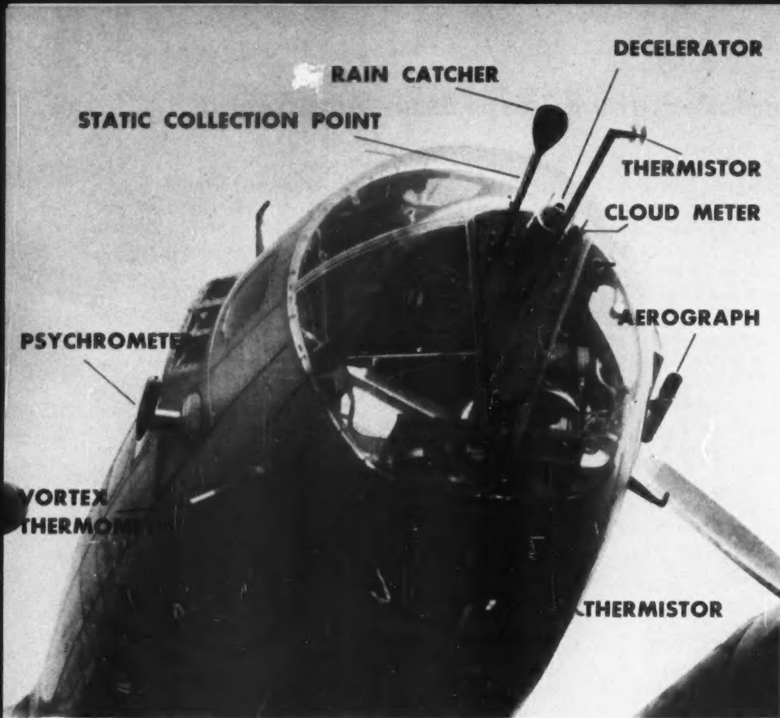
Flight Program

At the outset, and until June 1, 1947, Project Cirrus test flights were made by a plane from the Weather Squadron assigned to the Signal Corps. Olmsted Field at Middletown, Pa., was the base of operations.

It was soon discovered however that many delays in carrying out flights could be traced to this geographic separation of the Operations and Research Groups. Accordingly, in the summer of 1947, the Operations Group and all flight operations were transferred to the General Electric hangar at the Schenectady County Airport, Schenectady, NY.

At first the number of aircraft assigned to the project was meager, but eventually this situation was corrected. At one time as many as six planes were available—three from the Navy and three from the Air Force.

Active flight operations ran from the establishment of the project in March, 1947, until August, 1950, when the Operations Group was disbanded at the suggestion of the Research Group. This move was made in the interests of economy, for most of the objectives of the flight program had by that time been accomplished.



FLIGHT INSTRUMENTS mounted in the nose of a Project Cirrus B-17 include: static collection point to measure variations in the electrical potential of the atmosphere, a rain catcher to give average value of the precipitation in the air for approximately each 1000 feet of flight, and a decelerator to slow down the air and assist in sorting out rain, snow, dust, or cloud particles from the atmosphere as the plane passes through. A thermistor records temperatures, a cloud meter gives a measure of the average effective particle sizes in the various portions of a cloud, and an aerograph automatically records pressure, air speed, humidity, and temperature. A vortex thermometer measures true air speed (the usual type of thermometer is unsatisfactory for this purpose because of aerodynamic heating caused by the rapid movement of the airplane through the air), and a psychrometer gives wet- and dry-bulb readings

Photography

From the outset it was found that complete evaluation of the results of the various seeding experiments could not be made without taking pictures.

Both still and motion pictures were used. In addition, special techniques were adopted. For example, by means of lapse-time photographs (one frame every 2.5 seconds) it was possible to speed up movies to obtain a better grasp of the changes taking place in a cloud. (During the Puerto Rican test operation, more than 100,000 frames of lapse-time pictures were taken in color.) Also, by the use of stereoscopic equipment, it was possible to produce three-dimensional views.

Instrumentation

A considerable portion of the time and activity of Project Cirrus personnel was spent in the development of special instruments, tools, and equipment. As in any new undertaking in which there is little or no previous experience, many new devices had to be designed, or old ones had to be adapted to special requirements. Typical of the instruments used are those shown on this page installed in the nose of a B-17.

LABORATORY STUDIES

The interest and activity in cloud seeding and the fundamental physics of clouds, following the initial experiments, were so varied that it is difficult to give an orderly account of the progress in this field. Research both in the laboratory and in the atmosphere continued to reveal new and interesting facts.

Important laboratory studies involved the adiabatic expansion of gas in regard to the formation of ice crystals, chemical effects on ice crystals, spontaneous formation of ice crystals, structure of snowflakes, crystal growth and multiplication, raindrop studies, condensation nuclei, electrification phenomena, study of cloud types, and various analytical work.

Two of the studies are of major interest: ice nuclei and silver iodide.

Ice Nuclei

One of the most important phenomena associated with the study of the physics of clouds is the formation, distribution, and relative abundance of nuclei for the formation of ice crystals.

Considerable work was done in developing instruments and methods for detecting the presence of, and counting, such nuclei in the atmosphere. Relatively early in the history of the project, a station was established by Schaefer at the Mt. Washington Observatory for regular observations of the concentration of such ice-forming nuclei, and these observations continued for five years. Subsequently, Schaefer found in the laboratory that certain kinds of soils, when dispersed as a dust, were moderately good nuclei under certain atmospheric conditions.

At the present time the number of ice nuclei needed in a supercooled cloud to initiate a chain reaction is not yet known, but evidence found early in the history of the project, suggesting that a critical concentration is found in the range of 10,000 to 50,000 nuclei per cubic meter, has consistently been strengthened since.

A significant fact resulting from the Mt. Washington studies was the rarity of relatively high concentrations of active ice-forming nuclei in the atmosphere. If the observed results are a true representation of the average mean condition of the atmosphere, it is obvious that, by the artificial introduction of sublimation nuclei into the atmosphere, man possesses a powerful method of modifying many cloud systems.

One prolific source of ice-forming nuclei might be the Great Plains and the more arid regions immediately adjacent to the Continental Divide. Wind storms, "dust devils," and strong convective activity could easily account for the formation of ice-forming nuclei aerosols.

But it seems probable that the smoke produced by forest fires is a poor source of such nuclei. An attempt was made to determine the role that bacteria and the spores of fungi might play in this respect, and to evaluate the role of industrial smokes of various kinds.

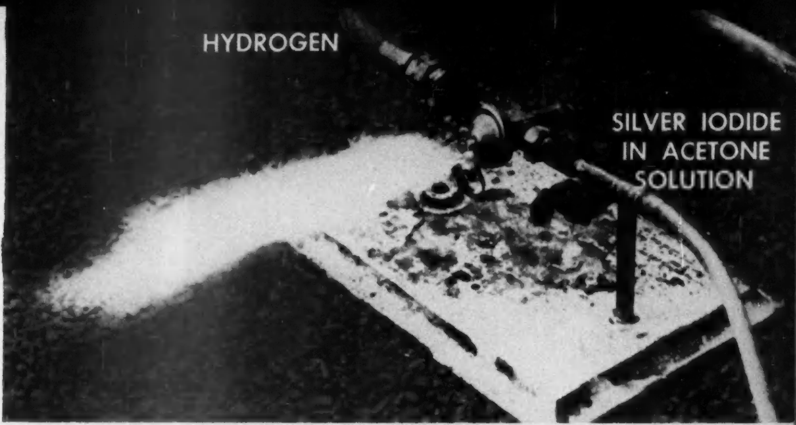
Silver Iodide

After the discovery that silver-iodide smokes serve as an excellent nucleus for the formation of ice crystals, the project was faced with the problem of finding some way of generating the smoke efficiently and in quantity. It was found that smokes consisting of exceedingly fine particles could be easily produced by vaporizing silver iodide at a high temperature and then rapidly quenching the vapor. This was readily accomplished by burning silver-iodide-impregnated charcoal or injecting a spray of silver-iodide solution into a hot flame (picture, above). Simple generators based on this principle were made that could produce 10^{14} nuclei per second—enough to seed from 1000 to 10,000 cubic miles of air per hour.

A very interesting fact discovered as the result of one of Vonnegut's studies is that silver-iodide particles do not react immediately as ice-forming nuclei when introduced into a supercooled cloud of water droplets. Even 50 minutes after introducing a smoke sample into the cold chamber, ice crystals could be seen to form at a measurable rate. The general conclusion reached as a result of this study was that the rate of reaction at −13 C is 30 to 40 times faster than at 10 C.

The nature of silver iodide is such as to suggest the possibility that its effectiveness as a seeding agent might be reduced by the action of ultraviolet and near-ultraviolet radiation from the sun. Accordingly, an investigation was made to determine its rate of decay under expected conditions of radiation in the free atmosphere. The results of work in this field, not only by Project Cirrus but also the New Mexico School of Mining and Technology at Socorro, suggested that far greater quantities of silver-iodide particles might be required for seeding operations under conditions of bright sunlight than would be needed at night or under conditions of cloud cover. But later work and observations indicated that the effect of sunlight might not be as bad as was forecast.

Experimental work showed that it is possible to convert supercooled ground fogs to ice crystals by releasing silver-iodide smokes.



SILVER-IODIDE SMOKE GENERATOR DEVELOPED BY VONNEGUT FOR USE ON THE GROUND

The significance of various types of clouds (pictures, page 16) and the role they play in weather phenomena were, of course, subjects of intense interest to Project Cirrus.

CIRRUS AND STRATUS STUDIES

A regular daily observation program began in 1947 to explore the possibility of inducing the development of cirrus-type clouds under clear sky conditions. It was believed that supersaturation with respect to ice probably occurs fairly frequently at temperatures warmer than −39 C in air devoid of foreign-particle nuclei. Lacking such nuclei, a considerable degree of supersaturation could develop, as is often shown by the generation of so-called vapor trails behind high-flying aircraft.

Several seedings were carried out from an airplane in clear air, using both dry ice and silver iodide. In clear air supersaturated with respect to ice, the seeding operation produced a cloud made of ice crystals (cover). The results of these operations indicated that, if the humidity is low, even at temperatures below −39 C, appreciable supersaturations with respect to ice can exist without the formation of ice crystals. Ice crystals can then be created however by seeding with either dry ice or silver iodide.

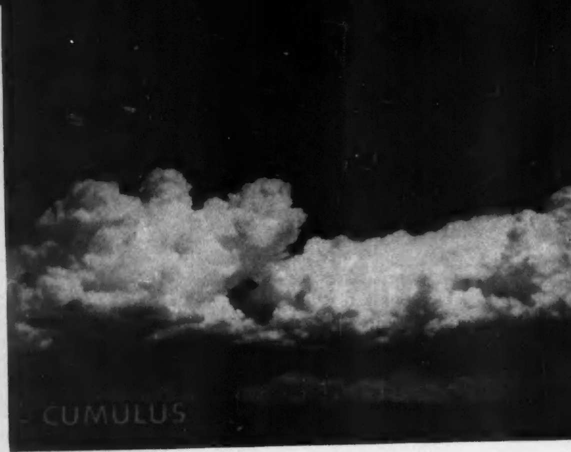
During the course of the project Langmuir described an action that he called "cirrus-pumping." This occurs when, with few or no nuclei present, a cumulus cloud rises to great heights. If it rises to a height when the temperature gets down to −39 C or thereabouts, minute ice crystals are formed in great numbers, almost instantaneously. These come into contact with the supercooled water droplets in the cloud and immediately cause them to freeze. This in turn liberates a large amount of heat simultaneously over the whole top of the cloud, and this upper part rises still further, forming a cirrus crown shaped something like a pancake.

The pancake grows in dimension and gets thinner, and it sometimes drifts gradually off to one side so that it assumes the general appearance of an anvil—a type of cloud characteristic of the tropics. One large cloud of this type, said Langmuir, might sometimes produce cirrus clouds which would spread over 10,000 square miles. Outside of the tropics, they may often occur during the summer in semiarid regions such as New Mexico, Arizona, or Idaho. (Picture 3 on page 9 is typical of an "anvil-top.")

Much more attention was paid to stratus clouds. In the flight test of March 6, 1947, now under the auspices of Project Cirrus, seeding was conducted on stratus clouds. Looking down on the cloud, it was observed, first, that a deep groove had been produced along the top of the seeded area (similar to picture, page 16), and snow fell. Soon the sky cleared in a spectacular fashion so that there was a cloudless area 20 miles long and 5 miles wide where the seeding had taken place, although there were no other breaks in the overcast in any direction. Further tests on stratus clouds produced similar results.

The conclusion was therefore reached in the earliest days of the project that cloud seeding could produce holes in stratus clouds. Thus a plane should be able to clear a hole for itself. The result would be not only to increase visibility but also to eliminate icing conditions.

It was soon found that a very useful technique (for observation purposes) in seeding stratus clouds was to seed



NOTE GROOVE IN STRATUS CLOUD DECK PRODUCED BY SEEDING AIRPLANE (ARROW)

in patterns—L shapes, race-track shapes, and Greek gammas. (Pictures, page 18.)

CUMULUS STUDIES

The most spectacular, fruitful, and controversial results produced by the activities of the project were those produced as a result of the work on cumulus clouds (picture, above). This work, which started in the earliest days of the project, continued throughout its duration and led to some other interesting activities.

Honduras

In 1948 and 1949, Langmuir visited Honduras, Guatemala, and Costa Rica to study tropical cloud formations, and particularly to learn what was being done by Joe Silverthorne, a commercial cloud seeder, in seeding clouds for the United Fruit Company. The work was being conducted for the purpose of testing the possibility of controlling rainfall, and particularly in the hope of stopping "blow-downs" that result from winds associated with thunderstorms, which occasionally destroy large stands of banana trees.

At Langmuir's suggestion Silverthorne tried out a number of experiments early in 1949 and made many worthwhile observations. It was sometimes desired to produce rain, and sometimes it was desired to prevent rain. On the one hand, by overseeding the top of a high cumulus cloud, rain would be prevented. The top of the cloud would float off into a higher altitude, where it would be blown away by the counter tradewind. If, on the other hand, the cloud was seeded just above the freezing level, heavy rain might be produced. Similarly, water seeding by means of water-filled balloons released from airplanes might dissipate a cloud and produce rain at low altitudes; but it seemed that in such instances dry-ice seeding would be much more effective.

The results of the flight on April 18, 1949, with Langmuir accompanying Silverthorne aloft in his Lockheed Lodestar, were so outstanding as to merit detailed comment. The following is extracted from an account of the flight by Langmuir:

> A large cloud was found which rose, I believe, to a height of about 25,000 feet, and we seeded it by making a series of short passes into the cloud at an altitude of approximately 21,000 feet—two pellets [dry ice] about one inch cubed being dropped into the cloud at 50-second intervals during these passes. The whole circuit of the cloud was made, and then the plane moved off a short distance, enabling us to see the effect produced.
>
> A band around the cloud, perhaps 500 or 1000 feet high, was observed which obviously consisted of ice crystals and which ultimately detached itself from the lower part of the cloud and floated off as a huge mass of ice crystals that could be seen for a long time . . .
>
> After the top of this cloud had turned to ice crystals and had detached itself, there was left under this cloud nothing but a group of lower clouds that reached only about 14,000 feet, which was below the freezing level. Later we flew down among these clouds and found that cloud bases had gone down from 12,000 feet to about 7000 feet. It was difficult to see whether any rain

". . . rainfall depends on . . . large particles of sea salt in the air . . ."

was falling . . . but from the lowering of the cloud base we concluded that rain had fallen from the lower part, while the top of the cloud had detached itself and floated off towards the northeast.

Shortly after seeding this cloud with 10 to 12 pellets, we picked out a smaller cloud nearby whose top reached about 20,000 feet and dropped one single pellet of dry ice one inch cubed on this cloud. About 8 or 10 minutes later we found that this whole cloud had changed to ice crystals. We flew through the ice-crystal cloud and verified the fact that they were entirely ice crystals. You could see them blowing into the cabin, and we also found that the cloud gradually dissipated. It probably rained out from the lower part of the cloud . . .

In other words, on this day we had beautiful examples of two effects that can be produced by seeding with pellets of dry ice. First, the seeding of the top of the cloud can cause the top to float off from the lower part. However, in this case some of the ice crystals reach the lower part of the cloud and cause rain to dissipate it. In the other seeded cloud, which was much lower and reached only a few thousand feet above the freezing level, the whole cloud rapidly dissipated as the upper part changed to ice and the lower part rained out.

The results of the flight of April 18 constituted for Langmuir a wonderful demonstration of the effectiveness of single pellets of dry ice for modifying large cumulus clouds.

Results in Hawaii

Further data, supplied from still another source, had some unexpected implications and results.

Early in 1947 a request for information on techniques of dry-ice seeding was received from the Pineapple Research Institute of Honolulu, Hawaii. This information was supplied by the research group of Project Cirrus, which had been supplying similar information to meet numerous requests since the published reports appeared of Schaefer's historic snowmaking flight over Pittsfield in 1946 (page 12). But in this case there was an unexpected aftermath.

In October, Honolulu newspaper accounts were received in Schenectady describing experiments carried out over the island of Molokai by Dr. L. B. Leopold and Maurice Halstead of the Pineapple Research Institute. A few weeks later, copies of a preliminary report were received from these two men, describing interesting results obtained by dumping dry ice into cumulus clouds *having temperatures above the freezing point.*

This was an important development. Although Langmuir had given some thought to the effect of seeding nonsupercooled clouds, he hadn't done much about it, and this new work caused him to restudy theoretical calculations he had prepared in 1944 in connection with the work at Mt. Washington.

He now had a new approach to the subject of weather modification: the growth of rain.

Rain Chain Reaction

The result was Langmuir's chain-reaction theory of rain production: A typical large drop of water grows in size as it falls through the cloud, growing faster and faster until it gets so big that it breaks up, producing smaller droplets. If there are rising air currents, the little droplets will be borne aloft into the cloud again, growing in size as they go, until they get so big that they start falling again. This process continues in a chain reaction, causing the whole cloud to go over into heavy rain. Under the right circumstances, according to this theory, seeding with water would be just as good as with dry ice.

The outgrowth of this, in turn, was considerable work by Project Cirrus to test Langmuir's theory and apply some of its principles in practice. For example, to determine the validity of several of the important phenomena that his theory postulated, laboratory studies were initiated of the growth of water droplets and of the behavior of droplets floating in the air.

The complete exposition of the theory by Langmuir was a beautiful example of theoretical analysis and mathematical calculation. Among other things, it reviewed the knowledge of cloud physics that had already been gained in the light of the new theory, summing up the probable behavior of both stratus and cumulus clouds. It went so far as to suggest that the chain reaction could, under the right conditions, be started by introducing even a single drop of water into a cloud, although the action would be most rapid when many large drops were introduced near the top of the cloud. It outlined the probable behavior of self-propagating storms. It postulated that the phenomena that occur in artificial seeding with dry ice or with water are essentially no different from those that occur spontaneously in nature. It concluded with the following significant summary:

> When we realize that it is possible to produce self-propagating rain or snow storms by artificial nucleation and that similar effects can be produced spontaneously by chain reactions that begin at particular but unpredictable times and places, it becomes apparent that important changes in the whole weather map can be brought about by events which are not at present being considered by meteorologists. I think we must recognize that it will probably forever be impossible to forecast with any great accuracy weather phenomena that may have beginnings in such spontaneously generated chain reactions.

Studies in Puerto Rico

During the Puerto Rico expedition in February, 1949, the carrying out of successful ground-air operations on three different occasions, using lapse-time photographs as part of the ground coverage, demonstrated conclusively to the members of the project the value of studying clouds that develop in definite cloud-breeding regions. Similar areas in the United States known to possess such developments were Albuquerque, NM, and Priest River, Idaho. Schaefer had already visited Priest River in July, 1948, and had studied the conditions there.

Despite the fact that no suitable clouds were found in Puerto Rico for testing out waterseeding techniques, much valuable information was obtained.

One of the important results of the expedition was the observation of the material effect of salt nuclei on the formation of precipitation in *thin* tropical clouds. Said one of the reports: "This seems, on first sight, to be of great importance in explaining the rain showers which are of daily occurrence and random distribution in the vicinity of Puerto Rico. Rarely is rain observed from such clouds in the eastern United States." Said Langmuir:

> Observations in Puerto Rico in 1949 and in the Hawaiian Islands in 1951 have shown that the rainfall depends on relatively large particles of sea salt in the air . . . Calculations of the rate of growth of salt particles indicate that it should frequently be possible to induce heavy rainfall by introducing salt into the trade wind at the rate of about one ton per hour in the form of fine dust particles of about 25 microns in diameter. The heat generated by the condensation may liberate

TWO MANHATTAN ISLANDS could be dropped through this L-shaped hole produced in a supercooled stratus cloud by seeding with dry-ice pellets. Progressive growth of seeded area is shown at right. Such a hole is free of dangerous icing conditions

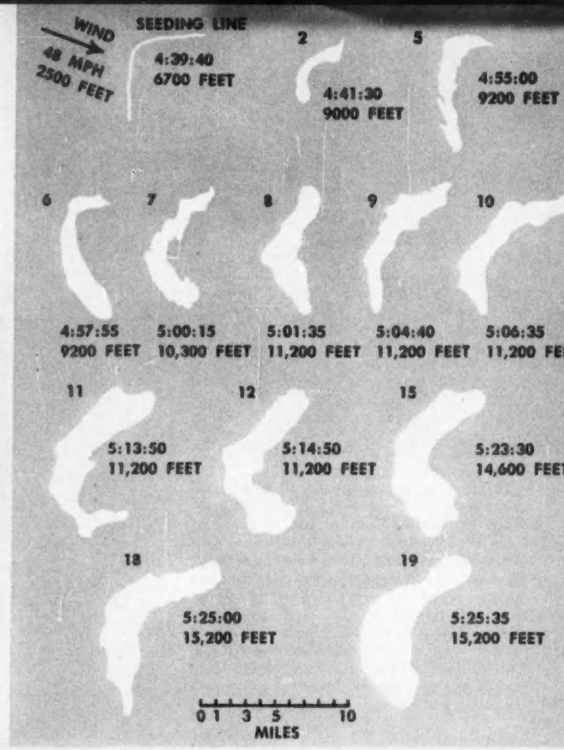


FIGURE "4" formed in stratus cloud deck. With such cloud modification, a plane should be able to clear a hole for itself to increase visibility, as well as to reduce icing conditions

RACE TRACK with 20-mile-long straightaways and 5-mile-long turns was formed by seeding a stratus cloud in such a pattern with dry ice. Many other such "figures" have been formed so much heat as to produce profound changes in the air flow and the synoptic conditions in neighboring areas.

New Mexico: Early Work

Although interest in cumulus clouds and thunderstorms was high among the members of the Research Group in 1948, the cumulus season passed in the vicinity of Schenectady without any significant flights being carried out. It was realized that the best results could be obtained from the seeding of cumulus clouds in a region where storms *originate*, rather than in a region which, like the Schenectady area, is *traversed* by storms. A strong recommendation was made that the New Mexico region be used as a base for experiments with cumulus clouds. This was seconded by Schaefer, who knew of the work being done in this field by Dr. E. J. Workman's group at the New Mexico School of Mines.

As a result, members of the project spent three days at Albuquerque during mid-October of 1948. A working arrangement was quickly made with Workman and his staff for radar tracking and photography of the tests to be made. Two seeding flights were made: one on October 12, the other on the 14th.

An exceptionally complete aerial photographic record was made on the 14th of the conditions of the cloud that was seeded from one of the planes, including 176 still photographs, plus pictures taken every 45 seconds of a group of instruments giving time, altitude, air speed, heading of the plane, and other vital information. Every time a photograph was taken of the cloud, another picture would be taken of the instruments. In this way an invaluable flight record was made of the test.

Four seeding operations were conducted on the October 14 flight. Langmuir's findings on this flight are to the effect that rainfall was produced over an area of more than 40,000 square miles as a result of the seeding—about a quarter of the area of the State of New Mexico. And substantially all of the rain for the whole of New Mexico that fell on October 14 and 15 was the result of the seeding operations near Albuquerque on October 14. Langmuir said, "The odds in favor of this conclusion as compared to the assumption that the rain was due to natural causes are many millions to one."

An early estimate by Langmuir was that about 100,000,000 *tons* of rainfall was produced. Later, using the rain reports from 330 stations given in a U. S. Weather Bureau publication, he concluded that the original estimate was unduly conservative. Said he: "The evidence indicated that the rain started from near the point of seeding shortly after the time of seeding and then spread gradually at a rate which at no place exceeded 22 mph, over an area of at least 12,000 square miles north to northeast of Albuquerque with an average of about 0.35 inches. This corresponded to about 300,000,000 tons."

Silver Iodide at New Mexico

So satisfactory were the tests conducted at Albuquerque in 1948 that it was decided to make a further study of cumulus clouds at that location in the middle of July the following year.

Previous to the arrival of the main body of the project, Langmuir and Schaefer investigated the general cloud situation in the various mountain regions nearby and decided the cloud systems along the Rio Grande Valley near Albuquerque were superior for their purpose to anything they could find in other parts of Arizona and New Mexico. In addition, the excellent radar, photographic, and shop facilities of the Experimental Range of the New Mexico School of Mines appeared to be ideal for carrying out the operations planned.

Between July 13 and July 22 a total of 10 flights were conducted, on eight of which two or three planes participated. Seeding operations with varying amounts of dry ice and the ground operation of a silver-iodide generator were the subjects for the flight studies.

Again the dry-ice seeding was successful, and the results of the various airborne seeding operations were quite satisfactory. But a new factor was introduced into this second expedition that put an entirely different aspect upon the results and had a tremendous influence on the course of future investigations and analysis. This was the effect of ground seeding with silver iodide.

As usual, close attention was paid to changes in weather conditions in order to observe any correlation between such changes and the dry-ice seeding. Although some silver-iodide seeding was being conducted on the ground (picture, page 15), this was disregarded by Langmuir, who was concentrating on the airborne dry-ice seedings. Consequently, when he noticed some weather conditions which could not be explained by the airborne seeding, he was puzzled.

Then he suddenly became conscious of the fact that Vonnegut had been trying to call to his attention the ground seeding of silver iodide, and he immediately realized that this might explain the discrepancies he had observed. Further study convinced him that this was, indeed, the case.

Not only that, but the results of the seeding activities in New Mexico the preceding year were reconsidered in the light of this development. And it appeared reasonable to conclude that the similar widespread effects produced in October, 1948, were the result of the silver-iodide seeding that was done at that time, rather than of the dry-ice seeding, which had been the previous interpretation.

Langmuir made, as was his habit, an exhaustive analysis of the available data and presented a striking summary of his findings from which the following is quoted:

> I wish particularly in this paper to describe the more widespread effects that were produced by the operation of the silver-iodide generator on the ground during July, 1949, near Albuquerque. The first seeding with silver iodide during this stay in New Mexico was on July 15, 1949, but the generator was not run for more than a couple of hours on each day thereafter until the 19th, when it was operated for a short time only, late in the afternoon. On July 20 it was not operated at all, but on the 21st it was operated for 13 hours, starting about 5:30 am and using 300 grams, or a total of 2/3 pound of silver iodide.
>
> Tests made by Dr. Vonnegut have shown that each gram of silver iodide dispersed under these conditions produced 10^{16} sublimation nuclei that are slowly effective at −5 C but very rapidly effective at −10 C.
>
> The new probability theory . . . has served as a valuable guide in devising an objective method of evaluating the distribution in space and time of the rain which follows the operation of the silver-iodide generator on the ground or in the airplane flights near Albuquerque. To illustrate the results, we will analyze the data obtained on two days, October 14, 1948 (Flight 45), and July 21, 1949 (Flight 110).

These days were chosen because large amounts of silver iodide were used, but no seeding was done on the immediately preceding days. Furthermore, the wind direction on both days was rather similar. On both days the Weather Bureau predicted no substantial amount of rain. Both mornings were nearly cloudless, and on both days SW winds prevailed from the cloud bases at 12,000 feet up to 20,000 feet. At lower and higher altitudes and later in the day there were also winds from the E, W, and NW. On both days, visual effects indicating thunderstorms and heavy rain over wide areas were observed a few hours after the start of the seeding operations.

Shortly before 8:30 am on July 21, 1949, a single large cumulus cloud began to form about 25 miles S of the field station near Albuquerque in a sky that was otherwise cloudless. This cloud was located near the Manzano Mountains, and the silver-iodide smoke had been blowing from the N about 10 mph so that it should have reached the position of the cloud.

Between 8:30 and 9:57 the cloud grew in height slowly at the uniform rate of 160 fpm. At 9:57, when the top of the cloud was at 26,000 feet (temperature −23 C), the upward velocity of the top of the cloud increased quite suddenly, so that the cloud rose 1200 fpm until at 10:12 it had reached 44,000 feet (temperature −65 C).

At 10:06, when the top of the cloud was 36,000 feet (temperature −49 C), the first radar echo return was obtained from the cloud at an altitude of 20,500 feet (temperature −9 C). The distance given by radar was 25 miles at an azimuth of 165 degrees, which was exactly where the cloud was found to be from visual observations. The area of precipitation in the cloud was about one square mile at that time and was deep within the mass of the cloud. Within four minutes, the precipitation area had increased to seven square miles, and within six minutes after the first echo appeared, the precipitation had extended upward to 34,000 feet, where the temperature was −43 C.

Lightning and Rain

The chain reaction in this cloud started at low altitude at a time and place which agreed well with the trajectory of the silver-iodide smoke.

The first flash of lightning was seen at 10:10, four minutes after the first radar echo was detected. In all, perhaps a dozen flashes of lightning formed from this cloud, and very heavy rain was seen to fall to the ground. The top of the cloud moved towards the W, but the lower part of the cloud, from which the rain was falling, moved gradually to the NE.

At 10:45, a second cloud about eight miles still further to the NE developed a radar echo, and from that time on during the day there was an increasing number of rainstorms giving very heavy showers in the neighborhood. During the late afternoon 1.2 inches of rain fell at the station where the generator was located. The phenomena observed near and at Albuquerque from the ground and the radio reports of exceptionally heavy rain at Santa Fe gave immediate evidence of the success of this operation in producing heavy rain.

(Some photographs of the July 21 operations are on pages 22–23.)

Langmuir's report then analyzes river flow and rain gage data for the region. In discussing the rain gage data, he says:

The rainfall data actually show . . . that the rainfall on both October 14, 1948, and July 21, 1949, was exceptionally high and could not have possibly been accounted for as the result of naturally occurring rain.

The map of the State of New Mexico, which represents about 120,000 square miles, was divided into eight octants or 45-degree sectors radiating out from Albuquerque. Then concentric circles having radii of 30, 75, and 125 and 175 miles were drawn on the map. This divided the whole state into 27 regions whose average distances and directions from Albuquerque were known.

"... a single large cumulus cloud began to form about 25 miles S of the field station . . . in a sky that was otherwise cloudless."

By entering on the map for each of these regions the average rainfall for Flights 45 and 110, a comparison could be made of the distribution of the rain on those two days. An objective way of evaluating the similarity between such two distributions is to employ the statistical device known as the correlation coefficient. This was found in this case to be $+0.78 \pm 0.076$. The chance that such a high value would occur among these figures if one set of them were shuffled giving a random distribution is only 1 in 10. [For further information on the correlation coefficient, see page 24.] Such close agreement in the distribution on two days could thus hardly be the result of chance. There must be an underlying cause.

We believe that the close similarity in distribution is dependent not only on the rather uniform synoptic situations over the states that prevailed on these days, but also depended on the fact that on both days the probability of rainfall depended on the nuclei that spread radially out from Albuquerque, the concentration decreasing as the distance from Albuquerque increased.

The next step was to investigate just what characteristics of this distribution were so similar on these two days. On each of the two days, nearly all of the rain that fell occurred within four of the eight octants. If each sector were divided into four to six parts arranged radially so that each would contain equal numbers of observing stations (about eight per region), the analysis showed that the average rainfall rose rapidly to a maximum in intensity about 30 miles from the point of seeding and that in each of the four sectors it decreased regularly as the distance from the source of the silver-iodide smoke increased. In fact, this decrease . . . indicated that the rainfall depended on the concentration of nuclei, and this, in turn, varied inversely in proportion to the distance from the source.

The agreements between the intensity of the average rainfall in separate regions and the theoretical equations were so good in each of the four sectors on October 14 and July 21 that the probability factors for each sector ranged from 10^2 to 10^3. Taking all the octants together, the probability factor rose to about 10^8 to 1.

For each of the eight octants that gave appreciable rain, the rain started progressively later as the distance from the source of the silver iodide increased. The advancing edge of the rain area thus moved from Albuquerque on July 21 at a velocity of about 15 mph and on October 25 at a speed of about 25 mph. These velocities agree well with the wind velocities observed at various altitudes.

Taking these results altogether, it seems to me we may say that the results have proved conclusively that silver-iodide seeding produced practically all of the rain in the State of New Mexico on both of these days.

The total amounts of rain that fell in the state on the two days as a result of seeding were found to be 800 million tons on October 14, 1948, and 1600 million tons on July 21, 1949.

If these units are not so familiar to you, I may say that on October 14, 1948, the total amount of rain resulting from seeding was 160 billion gallons and on July 21, 1949, 320 billion gallons.

Cost of Nucleation

Dr. Vonnegut has measured the number of effective sublimation nuclei produced by the type of silver-iodide smoke generator used in our New Mexico experiments for each gram of silver iodide used . . . One thus finds that, to get a 30-percent chance of rain per day within a given area in New Mexico, the cost of the silver iodide is only $1 for 4000 square miles.

If similar conditions prevailed over the whole United States, the cost per day to double the rainfall would be only of the order of a couple of hundred dollars. This verified an estimate that I made in November, 1947 . . . that "a few pounds of silver iodide would be enough to nucleate all the air of the United States at one time, so that it would contain one particle per cubic inch, which is far more than the number of ice nuclei which occur normally under natural conditions." Such a distribution of silver iodide nuclei "in the atmosphere might perhaps have a profound effect upon the climate."

It is interesting to note that 30 milligrams (1/1000 ounce) of silver iodide (cost 0.2 cent) when distributed in 30 cubic miles of air liberates as much heat when it enters into the bases of large supercooled cumulus clouds six miles in diameter as the explosion of an atomic bomb. This is the heat freed when the supercooled cloud changes to ice crystals.

The report then discusses a new theory that Langmuir had developed of the rate of growth of snow crystals in supercooled clouds containing known numbers of sublimation nuclei. After a brief exposition of the basis of this theory, he says:

> From the probability theory of the growth of showers from artificial nucleation, one obtains the result that the total amount of rain produced by operating a ground generator increases in proportion to the square of the amount of silver iodide used. Thus, with three times as much silver iodide one would get nine times the rainfall. The intensities of the showers would be no greater, but they would extend over a greater area.
>
> An analysis of the July 1949 rainfall in New Mexico, Arizona, Colorado, Oklahoma, Kansas, and Texas gives evidence that a band of heavy rain progressed in an easterly direction during the period of July 20 to July 23 from southern Colorado across the southern half of Kansas, where it gave three to five inches of rainfall in many places. It may have been dependent on the silver-iodide nuclei generated near Albuquerque between July 18 and 21 and in central Arizona between July 19 and 21.

The significance of the two test projects at New Mexico is thus apparent. They indicated not only the possibilities of silver-iodide seeding from the ground, but they suggested a widespread effect on the weather of the nation. And, as a result, the project conducted some experiments in periodic seeding that were destined to have a profound significance.

PERIODIC SEEDING

By this time, a rather close liaison had been established with Workman and his co-workers at the New Mexico School of Mines. So, in view of the significance of Langmuir's analysis of the effects and possibilities of silver-iodide ground seeding, and in order to test as soon as possible his ideas on periodic seeding, a schedule of operations on this basis was immediately established.

Starting in December, 1949, a silver-iodide ground-based generator was operated in New Mexico by the project on a schedule so planned as to introduce, if possible, a seven-day periodicity into the weather cycles of the nation. This schedule of regular weekly periodic seedings used about 1000 grams of silver iodide per week, and it continued with a few modifications until the middle of 1951.

From data gathered, Langmuir almost immediately found evidences of a definite weekly periodicity in rainfall in the Ohio River Basin. Again, he conducted an exhaustive analysis of the facts and performed elaborate mathematical calculations to determine the probabilities that these variations in weather could have taken place by pure chance.

His findings showed that, during 1950, there was a marked and statistically highly significant seven-day periodicity in many weather elements. The significance was so high, he said, that it could not be explained on the basis of chance; it could not have occurred from natural causes. It involved not only rainfall but also pressures, humidities, cloudiness, and temperatures over much of the United States.

"The total amounts of rain that fell in the state on the two days as a result of seeding were found to be 800 million tons . . ."

In his paper to the New York Academy of Sciences (October 23, 1951), Langmuir said:

> Almost immediately, that is, during December, 1949, and January, 1950, it was noted that the rainfall in the Ohio River Basin began to show a definite weekly periodicity. A convenient way of measuring the degree of periodicity was to calculate the correlation coefficient (CC) between the rainfall on the successive days during a 28-day period, with the sine or the cosine of the time expressed as fractions of a week, the phase being taken to be 0 on Sundays.
>
> Just before the start of the periodic seedings, the correlation coefficient CC(7) based on the seven average values for the successive days of the week of the 28-day period amounted to only 0.23, but in the next 28-day period the value of CC(7) rose to 0.91.

He went on to say that these periodicities in rainfall were evident at almost any set of stations in the northeastern part of the United States. For example, the periodicity during a 12-week period during the winter of 1949–1950 at Buffalo, NY, Wilkes Barre, Pa., and Philadelphia, was almost the same as that found in the Ohio River Basin, but with one-day phase lag.

Langmuir's paper continued:

> After May 1950, however, the periodicities became somewhat sporadic, although highly significant periodicities over large areas still occurred during more than half of the periods after July, 1950. Presumably the large amount of commercial silver-iodide seeding in the western states (not done with a weekly periodicity) masks the effects of the periodic seedings in New Mexico.

Later Periodicity

Early in 1952, during the course of their normal analyses of weather conditions throughout the United States, G-E scientists found evidence of a seven-day periodicity. The correlation coefficients were calculated and found generally to be of a very high order.

It was thought possible that this phenomenon might be caused by a corresponding periodicity in the commercial seeding going on in the West. After "tracing" the weather to a likely point of origin, the commercial seeding organization in that area was asked for a schedule of its seeding operations, which it willingly furnished. It was found that the commercial seeding had a periodicity corresponding to that observed in the weather.

Langmuir, in analyzing the data, observed that it would be difficult to determine cause and effect. In other words, it would be difficult to know whether the periodicity in weather was caused by periodic seeding or vice versa. For commercial seeding organizations do not seed at random times but rather choose for seeding those days when weather conditions are encouraging. As a result, although it might rain naturally, the seeding may increase the quantity of rain—and it may produce rain where none would have fallen naturally. On the other hand, if conditions are not right for rain, the operator does not seed.

Langmuir contrasted his findings with those reported in a paper by F. H. Hawkins, Jr., in the May, 1952, issue of the *Monthly Weather Review*, which indicated that as far as could be determined no seeding which was underway in the spring of 1952 could compare in periodicity with the marked spacing of rainfall at that time. Actually, Langmuir said, extensive analysis of seeding dates supplied by commercial seeding firms showed that artificial efforts to influence the weather in this way occurred in definite patterns throughout the West during this period, and that periodic seeding was at least 20 times heavier in May, 1952, than at any time before.

It is possible, also, that other commercial seeders farther east took advantage of favorable clouds produced

1 On July 21, 1949, near Albuquerque, silver-iodide seeding from the ground began at 5:30 am. This cloud began to form at 8:30. At 10:06 (above) a radar echo was returned

2 The first flash of lightning was seen at 10:10, followed by others. By 10:32 (above) the cloud had more than doubled in size and "very heavy rain was seen to fall . . ."

by these seedings and further intensified spaced rainfall as the weather moved east toward the Atlantic coast, Langmuir said.

HURRICANES AND FOREST FIRES

In addition to the normal studies and tests with which Project Cirrus concerned itself, there were two additional activities in which it engaged early in its history. One was a study of tropical hurricanes and the other was an attempt to cause rain in a forest-fire area. Both took place in 1947.

Hurricane Study

The hurricane study was planned by the various participating government agencies for the purpose of determining whether seeding operations could be carried out in such storms. These agencies hoped that the experience thus gained would permit the planning of further operations in the future, with the hope of possibly steering or in other ways modifying tropical hurricanes.

After a week of intensive organization and briefing at the beginning of the "hurricane season," Project groups were maintained in "stand-by" position, but the season progressed for some time without any suitable storms. Finally, on October 10, 1947, word was flashed from Miami, Fla., that a storm was forming below Swan Island in the Caribbean.

Plans were immediately activated and the next evening the Project's two B-17's were at Mobile, Ala. The storm had traveled with such high speed however that it was already crossing Florida. The unit flew to MacDill Field, Fla., the next day, joining forces with the 53rd Weather Reconnaissance Group. Plans were laid for take-off early in the morning of October 13. The storm was expected to be from 300 to 400 miles east of Florida by that time.

Here is an observer's account of the features of the storm, the seeding operation, and observed effects:

The storm consisted of an eye approximately 30 miles in diameter, surrounded by a thick wall of clouds extending from about 800 feet up into the cirrus overcast at 20,000 feet and being some 30-50 miles thick radially. Several decks (4 or 5) of stratified shelf clouds extended out from the outer wall, the uppermost deck having tops at 10,000 feet. These shelf clouds appeared as large areas (100-200 square miles) of solid, thin (1000-2000 feet thick) undercast, separated by large breaks through which the surface was often visible. An exceedingly active squall line, appearing as an almost continuous line of cumulonimbus with cirrus tops to an estimated 60,000 feet, was observed as a spiral extending out from the center-base at 20,000 feet near the outer wall, lifting to 35,000 feet at the edge.

Approach to the storm center was effected from the southwest, this course bringing the group into the storm's right rear quadrant. After a brief reconnaissance flight around the outer wall, the decision was made to seed a track over the uppermost cloud shelf and at a distance from the center sufficient to permit the control aircraft to fly contact 5000 feet above the seeding aircraft.

A formation intrail was used, with the seeding aircraft (B-17 No. 5560) leading at cloud top level. The photo-reconnaissance aircraft (B-17 No. 7746) followed the seed ship, 3000 feet above and ½ mile astern, with the control aircraft (B-29 No. 816) trailing 5000 feet above and 15-20 miles astern.

The report goes on to say that the storm was seeded at 19,200 feet and that during the 30-minute period 80 pounds of dry ice was dropped along a 110-mile track. In addition, two mass drops of 50 pounds each were made into a large cumulus top. Continuing:

Upon completion of this phase, all planes flew a reverse course back along the seeded track, taking visual and photographic observations. No attempt was made to penetrate through the wall of the storm into the eye or to seed in or near the above-mentioned squall line, owing to the failure of the group's homing aids (radio, compass, and visual flares). It was thought that such an attempt, although desirable, would likely result in a separation of the aircraft, with subsequent abortion of the primary mission.

Visual observation of the seeded area showed a pronounced modification of the cloud deck seeded. No organized trough was observed; rather, the overcast previously observed appeared as an area of widely scattered snow clouds. The disturbed area covered perhaps 300 square miles. No convective activity was seen to follow the seeding process at any time during the mission.

Schaefer, who was in the B-29, later said that "many suitable clouds for

3 Rain is clearly visible falling from the base of the cloud. This picture, taken from an airplane, shows the Manzano Mts. Throughout the afternoon there were further storms

4 During the late afternoon 1.2 inches of rain fell at the station where the generator was located (above). Some 320 billion gallons of rain fell over half the state

seeding operations occur in this type of hurricane . . . Owing to the complex structure of this 'old' storm, it is believed that a 'young' hurricane would provide much more satisfactory data for estimating the effect of seeding operations."

Langmuir made some interesting observations: "It seems to me that next year's program should be to study hurricanes away from land, maybe out considerably beyond Bermuda, out in the middle of the Atlantic . . . I think the chances are excellent that, with increased knowledge, something can be done. The stakes are large and . . . I think we should be able to abolish the evil effects of these hurricanes."

Operation "Red"

On October 29, 1947, a flight operation was carried out in Vermont and New Hampshire. At that time severe forest fires were raging uncontrolled in various parts of New England. Although it was not the policy of Project Cirrus to carry out such a widespread operation, it was felt that it would be worth the additional effort required to make such a flight for the experience to be gained, particularly since it would be possible to use Schenectady as the base of operations.

The flight was well planned from an operational point of view, but the results were not spectacular because of the absence over much of the area of suitable clouds—contrary to a forecast the previous day.

Seeding operations were carried out by two B-17's. The site of operation was over some of the stratus near Montpelier, Vt., and in the cumulus developments. Practically all of the latter showed the effect of seeding after five to eight minutes. Subsequent reports indicated the development of some fairly intense local showers along the flight path.

OVER-ALL RESULTS

The last of a series of government contracts ended September 30, 1952, after a little more than five years of the active life of Project Cirrus as a government-sponsored activity.

By that time all the early exploratory phases of cloud seeding and allied research concerned with the physics of clouds were virtually complete. So many other research projects had been stimulated that continued progress in the search for new and basic knowledge of weather phenomena seems assured.

Some of the possibilities inherent in cloud seeding as evaluated by Project Cirrus scientists are:

Widespread Weather Modification

The results of the various New Mexico tests, coupled with observations of the effects of other ground seeding with silver iodide, point to significant possibilities in the widespread modifying of weather conditions. Such work could easily have profound economic, political, and military effect.

Modifying Orographic Clouds

Orographic clouds, which form as moist air is forced to rise when it encounters a barrier such as a mountain range, are very common in mountainous regions, and they often form continuously for many days. Relatively little precipitation from them reaches the earth, except as rime deposits on trees and rocks, or as scattered snow crystals. If techniques could be devised to cause a widespread and effective precipitation of such clouds, the depth of the snow pack in the vicinity of mountains might be markedly increased. Such a result would be of great importance, since the snow pack on mountain slopes is very valuable in stabilizing the streams which flow from such regions. These streams, in turn, have great significance from a standpoint of electric power and water supply.

Producing Regions of Ice Nuclei

The production of specific regions in the free atmosphere containing high concentrations of ice nuclei or potential ice nuclei is an interesting possibility. Cold middle clouds, even though having no appreciable moisture, may be used as

THE CORRELATION COEFFICIENT

In Langmuir's analysis of the significance of silver-iodide seeding in New Mexico he made use of the statistical device known as the "correlation coefficient." This device is very useful in discovering similarities—or correlation—between two sets of figures. The key to its value lies in the fact that in algebraic multiplication like signs produce a plus value, and unlike signs, a minus value.

If you have two sets of figures and are attempting to evaluate the correlation between them, your first step is to set them down as two columns, X and Y. For example, suppose you are trying to establish the correlation between:

X	Y
2	1
4	3
6	5
8	7
10	9

The average of column X is 6, and the average of column Y is 5. Now you set up two more columns, x and y, each value of which is the deviation from the average of its corresponding capital-letter column, as follows:

x	y
−4	−4
−2	−2
0	0
+2	+2
+4	+4

Thus, as the first figure in column X was 2, it is 4 less than the average, which makes the first figure in column x −4. Similarly, the first figure in the original column Y was 1, which is 4 less than that column's average, making the first figure in column y −4 also.

It's now time to use this formula:

$$CC = \frac{\Sigma xy}{\sqrt{\Sigma x^2 \cdot \Sigma y^2}}$$

where CC represents the correlation coefficient and the sign sigma represents a summation. The other symbols are values of x and y that you have already established. For example, the value xy for the first figure in your column is -4×-4 or $+16$; the value for the second figure is -2×-2 or $+4$; and so on. The total of these values of xy is $+40$, as indicated in the sum of the column:

xy
+16
+ 4
0
+ 4
+16
+40

Inasmuch as the formula calls for values of x^2 and y^2, you make a column of these also, as follows:

x^2	y^2
+16	+16
+ 4	+ 4
0	0
+ 4	+ 4
+16	+16
+40	+40

By substituting numerical values for the terms of the formula you get:

$$\frac{\Sigma xy}{\sqrt{\Sigma x^2 \cdot \Sigma y^2}} = \frac{40}{\sqrt{40 \times 40}} = \frac{40}{40} = 1$$

In other words, your correlation coefficient for the two original sets of figures is unity; there is 100 percent correlation. Of course, you probably knew that from inspection in the first place, but a simplified example was chosen for purposes of explanation.

In actual practice the significance of the correlation coefficient depends on the number of figures in the two sets (X and Y). In other words, if X and Y each contain but one figure, any agreement or correlation between them would be just as likely to occur by chance as otherwise. But if X and Y each contain 50 figures, any correlation would be highly *un*likely to occur by chance.

To provide specific examples, it has been calculated that, in the case of a correlation coefficient of 0.60 for two sets of seven figures each, the odds that this correlation would occur by chance are 10 to 1. In the case of two sets of 28 figures each and the same correlation coefficient of 0.60, the odds that this correlation would occur by chance are 4000 to 1.

The number of figures being correlated are usually shown in parentheses following the correlation coefficient symbol, thus: CC(7). Langmuir obtained a value of CC(35) of 0.689, and values of CC(28) as high as 0.85.

"holding reservoirs" to store ice crystals until they come into contact with lower clouds of greater thickness or are entrained into cool or cold cumulus.

An example of this type of seeding occurred during the hurricane seeding project in October, 1947 (page 22). A relatively thin layer of stratus clouds covering an area of nearly 300 square miles was transformed to snow crystals. The subsequent fate of the crystals is still a moot question but, if a considerable region of them was entrained into the lower levels of a line of towering cumulus observed during the flight, the entrainment might have exercised a profound effect on the subsequent development of those cumulus clouds.

Similarly, the ice crystal residue from seeded, but small, cumulus clouds may be entrained at a low level into much larger cumulus forming in their vicinity. In this way an effect of considerable magnitude is produced as the supercooled regions are infected at a lower level than would otherwise be possible.

Modifying Stratiform Clouds

The widespread modification of stratus clouds by artificial means is possible at the present time whenever such clouds are supercooled. Under such conditions the clouds may be either further stabilized by overseeding, or precipitation may be triggered by using the optimum number of ice nuclei.

Observed results of the seeding of stratus clouds indicate that holes can be cleared in them by this method, which is bound to be of value in aircraft operations.

Modifying Supercooled Ground Fogs

Supercooled ground fogs formed by advection or radiation may be modified and even dispersed if care is exercised to prevent overseeding. Too high a concentration of ice nuclei introduced into such fogs might actually make them worse.

The prevention of the formation of ice fog is another possibility from the proper manipulation of seeding techniques. By introducing an optimum number of sublimation nuclei into the air in regions where such fogs are troublesome, it may be possible to continuously remove from the air the moisture responsible for the formation of this interesting but often troublesome type of ground fog.

"... it might be possible to build the storm into a much larger one ..."

The ice crystals generated in the vortices of airplane propellers plus the moisture added to the air by the combustion exhaust of the plane are the causes which generally lead to the formation of ice fogs at airports. Whether the removal of supersaturation with respect to ice by seeding methods will be of sufficient magnitude to prevent the ice-fogging effects produced by plane operations can be determined most conclusively by actual experiment.

Protection of Aircraft

There is no question about being able to modify icing clouds in the vicinities of airports and along heavily traveled air lanes. The problem, rather, is whether it may have a practical application. Low clouds that restrict visibility for landing approaches around airports, thick clouds in which planes must cruise as they wait for permission to land, and thick clouds that might deposit a serious icing load on the plane as it tries to climb up through them—these comprise hazards to safe aircraft operation. And whenever such clouds are supercooled, they may be profoundly modified.

The simplest means for carrying out such cloud modification would be to employ a plane well equipped for flying under serious icing conditions for patrolling the air lanes. The plane would report weather and cloud conditions and, whenever serious supercooled clouds occurred, would carry out seeding operations.

In flying through a supercooled cloud, the airplane itself may produce a fairly effective modification. The vortices which form at the trailing edges of the wings and particularly from the propeller tips form large numbers of ice crystals.

Modifying Orographic Thunderstorms

It may be possible that silver-iodide seeding from ground generators would be particularly useful in modifying orographic "towering" cumulus to prevent their growth into thunderstorms. By determining the air trajectory from the ground into the cold part of the cloud, potential ice nuclei may be sent aloft by a simple procedure. If subsequent experiments indicate that it is important to seed such clouds at a temperature only a few degrees colder than the freezing point, it may become necessary to use dry ice dispensed from planes or carried into the clouds by free balloons or projectiles.

Modifying Towering Cumulus

Towering cumulus also forms over flat country at times when the atmosphere is conditionally unstable. Dangerous and often deadly lightning strokes, torrential rains, destructive winds, and sometimes hail and tornadoes are the end products of such developments. Since the high vertical thickness of a supercooled cloud seems to be the basic requisite in the formation of a thunderstorm, it may be quite feasible by proper seeding methods to prevent this phase from developing.

The manner in which the seeding is done may produce a wide variation in the end results obtained. By seeding each cumulus tower with large numbers of crystals shortly after it rises above the freezing level, the cloud would be continuously dissipated and no extensive regions of supercooled cloud could develop. On the other hand, it might be desirable to seed such clouds to realize the maximum possible energy release. This presumably would involve seeding each cumulus tower just previous to the point of its maximum development. If this could be done effectively, it might be possible to build the storm into a much larger one than would develop under natural conditions.

Preventing Hail

The possibility that hailstorms might be prevented by seeding techniques is of considerable economic importance. A great amount of basic information is needed on the various properties of storms that produce hail. In some parts of the country where severe hail damage is frequent, storms are formed over certain mountain ridges and peaks that serve as cloud breakers. Such clouds should be particularly suited for modification by ground generators, since the air trajectory is definitely related to the flow of air up the mountain and into the clouds.

APPARENT LIMITATIONS

As in any of the physical phenomena, there are definite limitations to the degree in which experimental meteorology may be employed in modifying clouds in the free atmosphere. Some of these apparent limitations may disappear as our knowledge increases, although most of the restrictions now recognized are imposed by known physical laws.

Fair Weather Cumulus

Foremost of these restrictions is the factor of cloud type and size. Certain clouds, such as the fair-weather cumulus, have such a small volume and restricted area that, even though they are easily modified when supercooled, their total liquid-water content is inconsequential. Another complicating factor is that the air below larger clouds is sometimes so dry that a considerable amount of precipitation evaporates before it reaches the ground.

Warm Ground Fog

Another type of cloud that is difficult to modify is the warm ground fog formed by radiation or advection. Such fogs are often extensive and of considerable economic importance, especially from the standpoint of aircraft traffic control. But the natural structure of a fog precludes any simple method of modifying it. Generally, the vertical thickness is not more than 100 meters or so, with a cloudless sky above. This rules out the possibility of modifying from above by forming precipitation in higher clouds to "rain out" the fog. (But supercooled ground fogs may be modified, as explained previously.)

Drought

Another weather situation where no method of relief is now apparent is in the case of drought. This condition generally results from the stability of a complex weather pattern in a manner which, at present, is not well understood. Drought is generally accompanied by either cloudless skies or clouds of small vertical and horizontal development, because of strong inversions or thick layers of dry air.

Convergence

The development of convergence is an important feature in the formation of appreciable amount of rainfall in many parts of the world. As a rule, such developments are generally accompanied by the occurrence of natural precipitation that continues so long as the con-

CAN MAN CONTROL THE WEATHER?

Can man now control all phases of the weather?

No. Man is just beginning to understand the first principles of weather modification. It appears that he can cause long-range effects on the weather under certain conditions in about the same way that a small boy might affect traffic over a relatively large area near New York City on a summer Sunday afternoon by dropping a handful of tacks at a strategic highway intersection. But there is a reason to believe that man can eventually learn to produce useful weather modification.

Can man create clouds?

Under controlled conditions in the laboratory, with an atom bomb out-of-doors, or by seeding supersaturated air under certain conditions—man can create clouds. But these clouds cannot produce precipitation of any significance. However, if man can, under certain conditions, modify weather by seeding, then, because of the large amounts of energy involved in the precipitation phenomena, it is certain that clouds will be created at remote locations. But it is unlikely that these clouds could ever be positively identified as having resulted from the original seeding. At a predetermined place and time man cannot now create clouds of any significance.

Can man now break a drought by cloud seeding?

The usual cause of droughts—or floods—is the persistence of clear—or rainy—weather. Any weather modification techniques that would change those conditions would be of help. But in a drought area it doesn't seem possible that seeding will cause any important changes in the weather conditions. It may eventually be possible, however, to affect the weather in such an area by large-scale seeding operations at distant points.

vergent movement is present. About the only thing that artificial modification of clouds might do under such atmospheric conditions is to initiate the precipitation cycle a few hours before it would start naturally or, under some conditions, to delay the onset of precipitation by overseeding.

LEGISLATION

For various reasons, national legislation has been suggested, and actually introduced, to regulate and control artificial weather modification. S.222 specifically covered proposed regulation and control, while S.798 authorized the Secretary of Agriculture to conduct research and experiments.

Since those bills were introduced, another was drafted and introduced in the Senate, 82nd Congress, second session: S.2225. This bill would create a temporary advisory committee of nine persons to study and evaluate experiments in weather modification, continuing no longer than July 30, 1955. The committee would report to Congress at the earliest possible moment on the advisability of the Government regulating, by means of licenses or otherwise, the activities of persons attempting to modify the weather. The bill was referred to the Committee on Interstate and Foreign Commerce on October 8, 1951, and reported out with amendments on May 12, 1952.

The General Electric attitude toward legislation was summed up at the above hearings by Vice President and Director of Research, C. G. Suits, and by Schaefer and Vonnegut, who accompanied him to the hearings. Said Suits, in part:

> It is my considered opinion, however, that the results of the most recent work are of the very greatest importance to the Nation. We have at hand a means of exerting a very considerable degree of control of weather phenomena. Precisely how much control can be accomplished will come from further study. Much work remains to be done, and it would be a national tragedy if legislation did not provide a proper framework for developing the full potentialities of weather modification methods. It would be hard to imagine anything more important to the country than weather modification and control.

Another extract from the Suits statement:

> I wish to be very clear on one point. The work my Company has done in this field, initially at our own expense and more recently under a Signal Corps contract with the participation of the Office of Naval Research and the United States Air Force, has had no single practical application within the Company. The work originated as an unexpected result of one of the many fundamental investigations which we undertake in the search for new knowledge. It was continued because the leaders of my Company and responsible representatives of the Government believed that the possibilities of weather modification might be of great importance to the nation as a whole. On December 27, 1950, my Company announced that for the present and until further notice it does not intend to enforce any of its patents relating to weather modification by the artificial production of snow and rain.

Other aspects of the need for legislation were voiced at that time by Schaefer:

> It is very important, in my opinion, that weather studies involving experimental meteorology be conducted in such a manner that all of the modifications attempted by man-conducted seeding operations be known and controlled. If this is not done, the effort of attempting to understand the reactions which occur is a hopeless one . . .
>
> It is obvious that some type of national legislation is of the utmost importance at this time to protect the public in the future from unscrupulous individuals who would play on the gullibility, hope, or desperation of individuals or groups in need of water or other relief from an undesirable climatic situation.

Vonnegut, in his statement read at those hearings, also urged the adoption of suitable legislation. In addition to the reasons voiced by Suits and Schaefer, he added others:

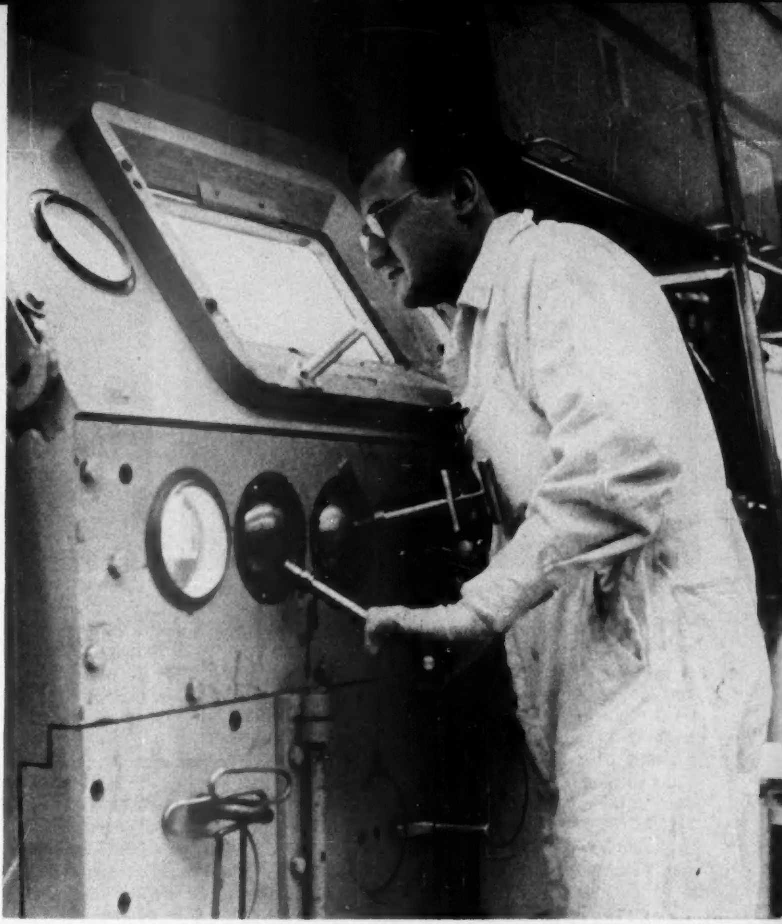
> The problems of weather control are so large and of such Nationwide importance that only Federal legislation can insure that this powerful new tool will result in the greatest good for the largest number of people. In the absence of this legislation, I believe that the development of the benefits to be derived from cloud seeding may be greatly retarded or prevented and that possibly much harm can result from storms, droughts, or floods produced by uncontrolled seeding.
>
> Theory has predicted and experiments are confirming the fact that a few pounds of silver iodide released into the atmosphere in the form of fine particles can exercise a profound influence over the weather hundreds of miles away from the point of release. Clearly no private individual or group can be permitted to carry on operations likely to affect weather conditions over thousands or hundreds of thousands of square miles.

As of October, 1952, no national legislation had been enacted to cover any of the needs outlined in the foregoing.

It is not, of course, easy to predict the ultimate results of the work done by Project Cirrus. But it does seem certain that the pioneering and spectacular work of the General Electric scientists in cloud physics, cloud seeding, and weather modification will eventually have a profound influence on domestic and world economics. Ω

LOOKING IN ON DANGEROUS OPERATIONS

By J. M. HOLEMAN



LEADED GLASS PROVIDES BETTER SHIELDING THAN SAME THICKNESS OF STEEL

Each day there's an increased demand for equipment to remotely view dangerous operations. Atomic energy installations, ammunition and explosive programs, testing stations for the development of rocket and jet engines—these and others find it indispensable to their activity.

Chief among hazards at the Hanford Works, operated by General Electric for the Atomic Energy Commission, is radioactive emission. And precautions taken there depend on the type and intensity of radiations. Most frequent of all is highly penetrating gamma radiation—similar to powerful x-rays.

Looking in on operations conducted behind barriers that shield out radiation is the problem. These may be concrete walls or metal barricades, and often as not they're located some distance from the operator. Whatever its type, viewing equipment can't allow dangerous radiations to escape into areas occupied by personnel.

The two fundamental principles on which viewing equipment is based are *filtering* and *reflection*.

Glass and many other transparent substances are good filtering materials. Although easily penetrated by light in frequencies to which our eyes are sensitive, they're much less "transparent" to atomic radiations. You can therefore obtain the desired filtering action by interposing a thick layer of glass or water—or some other clear but dense material—between the radiation source and the observer.

The quality of stopping gamma radiation is roughly proportional to the thickness and atomic number of the filtering material. (Optical transparency depends on entirely different factors.) Glass, the most logical filtering material, may consist of any number of fused metallic oxides, and have a wide range of properties in combination with high visual transparency. Water and solutions are also effective, but specific protection of plastics is low.

Mirrors reflect visible light efficiently, but not atomic radiation. (There may be a weak secondary radiation that can be removed by filtering or rescattering.) Lenses will focus and concentrate light but not atomic radiations. Accordingly, by building a viewing system with two or more bends containing reflecting mirrors, you are able to trap out unwanted radiations—and still transmit a good deal of light from the scene.

Purely for classification purposes three types of viewers applicable to radiation work are recognized.

- Window—either of solid glass or a liquid-filled cell.
- Mirror—consisting of a series of mirrors to allow viewing around barricades.
- Periscope—a combination of a mirror viewer and optical system.

First, let's look at the different kinds of . . .

Window-type Viewers

Plate Glass—Windows are made of many layers of ordinary plate glass, either assembled dry or laminated with a liquid cement to reduce internal reflections.

FOOT-THICK WINDOWS PASS 60 PERCENT OF THE INCIDENT LIGHT

VERTICAL PERISCOPE LOOKS DOWN INTO A RADIOACTIVE ZONE

Plate glass itself consists of about 85 percent silicon dioxide, along with oxides of light metals such as sodium, potassium, and calcium. Atomic numbers of all these elements are so low that the glass makes bulky shielding for even moderate amounts of gamma radiation. And for many purposes it offers protection equivalent to the same thickness of concrete.

Lead Glass—It's possible to dissolve large amounts of lead oxide in glass melt and produce a series of leaded glasses of various densities.

The most important development in this line is the manufacture of a lead glass with a shielding equivalent slightly greater than the same thickness of steel. Windows as large as 18 by 24 inches and a foot thick have been used for some time. Such a viewer passes about 60 percent of white light incident upon it. The high refractive index of the glass makes objects on the other side seem closer than they are, at the same time allowing a wide field of view—sometimes up to 180 degrees.

Excellent photographs taken through these windows will stand considerable enlargement. And, when wanted, telescopes or binoculars are used to get a magnified view. Even microscopes of powers varying up to 1500 times are used, and presentable pictures are made at the highest magnification.

Water Cell—For many purposes the plain water-filled cell, enclosed in windows of plate glass, has a shielding equivalent to solid concrete.

Viewers containing a layer of water six feet thick are built, but show a light transmission of only 25 percent when new. And with the growth of algae and scum in the water, they may deteriorate still further.

A viewer designed with a large window on the *side away from* the observer will give a fairly large field of view. This leads however to *prismatic* effects, making sharp seeing impossible. Such aberration is caused by different wave lengths of light being refracted varying amounts because of the large water-prism. It can be eliminated through use of monochromatic (one-color) lighting—such as sodium-vapor street-lighting units. When this type of illumination is employed, the images show excellent clarity even at the extreme edges, but color vision is impossible. Optical aids and photography may be used with water-filled viewers under certain conditions.

Solution-filled Cells—A highly soluble, colorless, metallic salt of high atomic number will increase the density and shielding protection of a water-filled viewer.

Only one salt has met with any success: zinc bromide. Most of the others are insoluble, expensive, poisonous, corrosive, and unstable toward light; or they tend to crystallize with a drop in temperature.

Water Tanks—Where conditions permit, the whole operation can be submerged in a water tank and observed and manipulated through the water.

This method greatly simplifies the handling, as well as the viewing problem. For a close view, ordinary binoculars or special long waterproof binoculars that dip into the water can be used. Or, we can use a watertight periscope or microscope that goes all the way to the tank's bottom.

Lead glass windows used at Hanford are shown in photos on pages 27 and 28. Both the old type—laminated of 20 or more sheets of lead x-ray glass with a total thickness of about 6 inches—and solid lead glass windows are employed.

The laminated models are cemented with a liquid of high refractive index, and show only minor internal reflections. Solid windows are of several sizes, the smaller cast of a single piece of dense glass, the larger of two or more pieces. There's no evidence that radiation has affected these windows after several years' use.

Much use is made at Hanford of the water-filled cell, equipped with windows of tempered glass. These windows are of the same material used to make glass doors for public buildings, only they're thicker and stronger and regarded as unbreakable. Some are designed with a large window on the work side and a smaller one on the viewing side, providing a wide field of view for observers. A remotely controlled mirror can be positioned to obtain back and side views of the work. Special binoculars, with improved three-dimensional effect, allow

HORIZONTAL PERISCOPE VIEWS ANY WALL OF DANGEROUS AREA

DOUBLE PERISCOPE SIMULTANEOUSLY INSPECTS SIDES OF OBJECT

sharp depth perception at considerable distances.

Concrete tanks filled with water are used for a number of operations at Hanford. If the water is kept circulating, it's usually quite clear. Because water has a higher refractive index than air, the bottom appears closer than it is and observers get a better view. Observers stand on platforms at the tank's edge and manipulate material with long tongs.

When desired, the observers use binoculars. However, reflections from the water's surface may be troublesome, and agitation of the water by others working nearby will ruin the image. If so, a glass-bottomed wooden box floating on the water will give a smooth surface to see through.

It's possible to combine the functions of the binocular and glass-bottom box into one instrument. This is a special binocular six feet long, built like a pair of periscopes, with watertight windows over the lower end. For still higher magnification an underwater telescope is used.

At times it's desirable to make even closer examinations in the water tank, at the same time eliminating two limitations of a thick water layer—its slight blue color and turbidity. For this purpose a long periscope permanently mounted in the tank is used. Its objective lens is near the tank's bottom, protected from the water by a flat window. Samples held four feet away from the lens appear full size in the eyepiece—at six inches distant they're magnified 10 times.

Now that we've covered window types, let's turn to . . .

Mirror-type Viewers

Where not feasible to see *through* a barrier, you can take the alternative of seeing *around* it.

Mirrors are ordinarily used in pairs because a single reflection produces a reversed image. The most difficult feature is to obtain a large field of view, particularly if the system is of any length. A few minutes of experiment will show that if a wide field of view is needed, and if separation of mirrors is at all great, they must be large.

The devious light paths in mirror-type viewers often lead to troublesome increases in apparent distance between observer and work area. Then it may be desirable to magnify the image with a binocular or telescope. But these instruments also magnify the defects in glass of ordinary mirrors, and emphasize double reflection from their surfaces. Therefore, the use of a front-surface mirror is called for.

Mirrors of this sort are limited in size, easily damaged, and expensive. To our knowledge the largest front-surface mirror available is 30 inches in diameter.

The Hanford Works employs few mirror-type viewers. At present they're only used for the simple job of looking or photographing over a low wall or barricade.

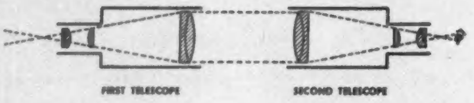
A viewer with greater flexibility than the types we've discussed so far is the . . .

Periscope-type Viewer

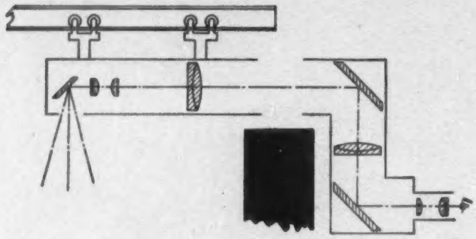
You can regard a periscope as a mirror-type viewer to which an optical system is added, reducing its size and providing certain other advantages. Periscopes are noted for their versatility because they can be made to show almost any magnification or field of view, and they can scan, rotate, or extend. (See drawings on the next page.)

Optical—A periscope consists of two, usually identical, telescopes arranged with their objective lenses toward each other. (Eye lenses and an object lens make up a telescope. It can be made with any diameter, length, or magnifying power by choice of suitable lenses.) Because of its symmetrical design, a periscope has the optical effect of transporting your eye to the opposite end of the instrument. With this symmetrical system there's no magnification in the proper sense of the word. But since your eye is in effect closer to the work, an enlarged view and different perspective are obtained.

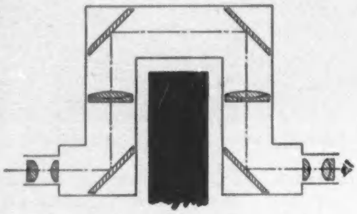
Magnification—This is acquired in either of two ways: The periscope objective is made to approach the object to be viewed closely, giving the same effect as when an object is brought close to the eye (magnifications of 10 times are easily achieved with a unit power telescope); or, the periscope is



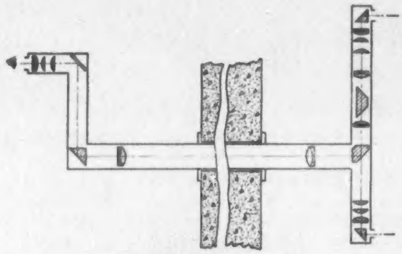
PERISCOPE



EXTENDABLE PERISCOPE



PERISCOPE WITH MIRRORS



DOUBLE-HEADED PERISCOPE

made *unsymmetrical*. If, for example, you use a periscope objective with four times the eyepiece's focal length, the instrument magnifies four times.

Variable magnification is obtained by equipping the periscope with a rotating turret of lenses of different focal lengths and magnifying powers. These can be changed by remote control. It's possible therefore to make a periscope show a wide field of view for one operation, and a telescopic effect for another.

Similar mechanisms have been engineered in a compact space, and with parfocal lenses so that the image is always in focus at any power. Changes from one lens to the other are almost instantaneous and can be made in any order.

Continuously variable magnifying power is obtained in at least two ways. First, if the object is close at hand, the periscope can be made to approach it for a closer and more magnified view. Second, it's possible to replace a series of different focal-length objectives with a single variable focal-length objective lens. They are more cumbersome and expensive however than the usual objective lenses. (The Zoomar television camera lens has a continuous range of magnification of about six times.)

Field of View—The *real* field of view of an optical instrument is an angular measure of the actual area covered. And the *apparent* field of view is that area visible in the eyepiece as seen magnified by the lenses. The area of a field viewed is measured in spherical degrees—and, an angle of 120 degrees covering about six times the area of an angle of 50 degrees.

The apparent field of most periscopes assembled from stock parts is about 50 degrees—nearly the same field of a good binocular, telescope, or wide-field microscope. Usually this is sufficient to give you a fair feeling of image size. With specially designed optics it's possible to have an apparent field of 70 degrees or greater. (Such optics are especially necessary in search instruments like aircraft periscopes, where gunners scan the sky for enemy aircraft. They're useful to pick up and follow rapidly moving objects but not necessary for viewing relatively static ones.)

Magnifying power relates real and apparent fields of view. If the apparent field is 50 degrees and there's no magnification, the real field is the same. At five times magnification the apparent field is still 50 degrees, but the real field is only one-fifth this, or 10 degrees. Real fields of periscopes depend on their apparent field (usually 50 degrees) and magnifying power, and may be anything from less than a degree to 50 degrees. If a larger angle of view is needed, you get it at the expense of demagnification. One such lens that finds considerable use has a real field of 120 degrees and negligible distortion. It closely approximates the peripheral vision field of both eyes.

If a still larger field is required, it's possible to use lenses giving up to 180 degrees coverage, but considerable distortion results. The better solution to this problem is to arrange the instrument to scan the large area with any one of the scanning mechanisms available.

Some difficult viewing problems were solved through means of a rather ordinary periscope and a mirror, the latter held in a remotely operated manipulator. Several such mirrors allow the periscope to simultaneously view different aspects of the same operation.

Extendability—One form of the periscope's versatility is it's ability to extend, or "stretch." Large lenses that were called "objectives" of a telescope are called "erectors" of a periscope. And because the light rays between these are parallel, you can vary the separation between them without altering the focus, magnifying power, or image quality.

Speaking again in terms of two telescopes, one telescope is stationary and contains the eyepiece, while the other telescope contains the objective lens and moves on a track or rail. Periscopes are built in which the extendable portion moves 45 feet.

Scanning—Just as it's possible to place a mirror before your eye and, by tilting at different angles, see in various directions—so it's possible to use the same effect to scan the field of view of a periscope. Optically, the action of scanning can be compared to moving your eye within its socket.

A properly designed scanning mechanism is compact, uses a small prism in most cases, and scans the center of a field of view over an angle of about 100 degrees. It's also feasible to use a double-scanning prism. The prism allows viewing in either direction, the effective angle in this case becoming 200 degrees. Several electrical or mechanical devices may provide for rotating the prism about its pivot.

Rotation—If required to view an area larger than can be conveniently covered by scanning, you may find it necessary to rotate the periscope. For example, take a periscope that penetrates the wall of a room and is equipped for scanning and complete rotation as well. It will be capable of inspecting the entire room—walls, floor, and ceiling.

While most desirable to rotate the instrument as a whole, it's not always practicable because of mechanical complications. Rotation of only the scanning head or objective achieves the same result but introduces a new problem—namely, "twisting" of the light path that causes the images to rotate also. In some positions the image will be seen on its side, upside down, or at an intermediate angle.

There are however several mechanical and optical means of eliminating this twisting effect. One calls for counter-rotation of some other element in the system so that the light path is no longer twisted. (In long or extendable instruments where mechanical shafting is impractical, you can obtain the rotation and compensation by self-synchronous electric motors.)

Elbows—Bends in the periscope can be placed at any point through use of suitable mirrors or prisms. In general, it's simpler to standardize on right-angle bends because these prisms are readily available. Odd-angle and even variable bends can be accommodated. Many periscopes are made that go around two or more corners, and some pass through zig-zag passages.

Multiple-purpose Periscopes — Sometimes you'll find it necessary to view both sides of an object. While the obvious solution is to use one periscope and a mirror or two separate periscopes, it's also possible to build one with multiple viewing heads. The multiple images are presented simultaneously in a split field, as done in some military range finders, or successively by means of a selector. Optically, the selector operates as a switch on a railroad. It consists of mirrors or prisms that are made to enter or leave the optical train at will, thereby deviating the light path along a desired course. Such a device can be remotely operated almost instantaneously.

Periscopes can be used with almost any optical instrument. As mentioned earlier, their optical effect is to transfer your eye from one end of the device to the other. For example, it's practical to place a microscope before a periscope's objective lens and get satisfactory results.

Photography through a periscope isn't recommended if there's another way to do the job. There are several reasons why ordinary periscopes, though they may show excellent visual images, make extremely poor photographs.

Periscope lenses, usually not of photographic quality, produce curved images. These images are satisfactory for visual use because the eye is insensitive to even a considerable amount of curvature. But a camera using flat film cannot handle them because it's impossible to get the whole image in focus at one time.

An alternative is to send the camera into the area to be photographed. Where this solution isn't practical, a special photographic periscope is needed.

To convert a periscope to photographic use and attain good results, it's necessary, among other things, to replace all or most of the lenses with photographic ones of equivalent focal length and apertures. Lenses of this kind are considerably more expensive and will in general show a narrower angle of view.

No attempt will be made to describe all varieties of periscope viewers in use at Hanford. A brief description of a few will suffice to show you their general application.

Short light-equipped small-diameter periscopes are used to inspect centrifuge baskets and the inside of tanks and welds.

Longer periscopes, equipped with a synchronized searchlight for scanning and rotation, are used to inspect large tanks for foreign objects or equipment operating in them.

Portable periscopes that come apart in short sections view around corners, up stair wells, and into otherwise inaccessible places.

Inspection periscopes are permanently installed in areas needing periodic surveys. These instruments allow a wide field of view, are easily aimed at any part of the job by hand controls, and have multiple heads with automatic selectors so that any area can be viewed from the best perspective.

Maintenance periscopes have one end attached to the operator's booth, while the other end is remotely controlled. It follows repair equipment, providing either a wide field or magnified view.

Borescopes, long slender periscopes, are used to inspect the interior sections of a pipe. A special type makes a moving picture record of the pipe's entire interior surface for corrosion studies.

Each of the basic viewers described—window, mirror, and periscope—does a particular job best. None are without disadvantages. For instance, window- and mirror-type viewers allow several persons to view an operation at one time, while the periscope-type viewer is usually restricted to a single eyepiece. On the other hand, periscopes have far greater flexibility in magnification range and ability to follow moving objects.

And so, to take advantage of the best in each, more than a hundred different kinds of viewing systems are used at Hanford. Ω

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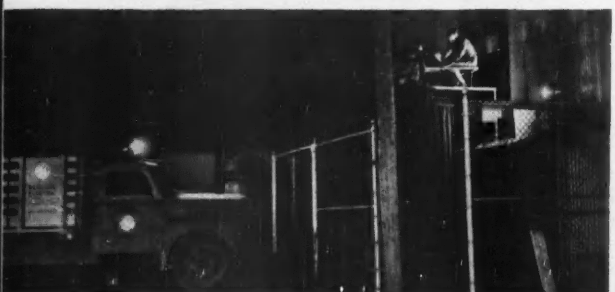
As an engineer in the Instrument Group of the Manufacturing Section, Nucleonics Division, Hanford Works, Richland, Wash., Mr. Holeman designs optical equipment and supervises the Optical Shop. Five years ago he joined General Electric and this year received the Coffin Award for his contributions in new optical equipment.

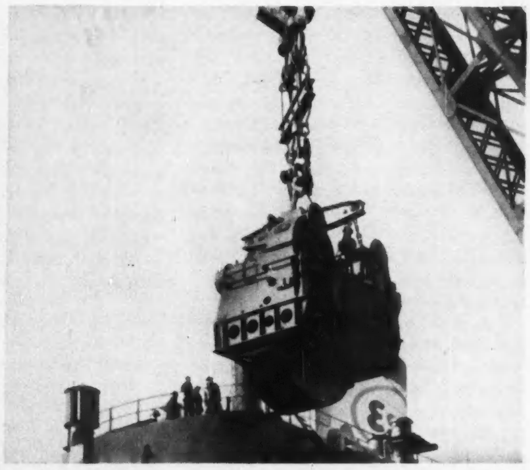
ENGINEERING REPORTS:

FIRE AND FLOOD, like Kansas City's 1951 disaster, signal the immediate mobilization of the G-E Apparatus Service Shops and Field Engineers to help supply power, heat, water and sewage disposal needs. Techniques for restoring damaged electric equipment to serve vital community and industrial requirements have been greatly speeded up and improved by G-E service engineers.

These engineering "minute-men"

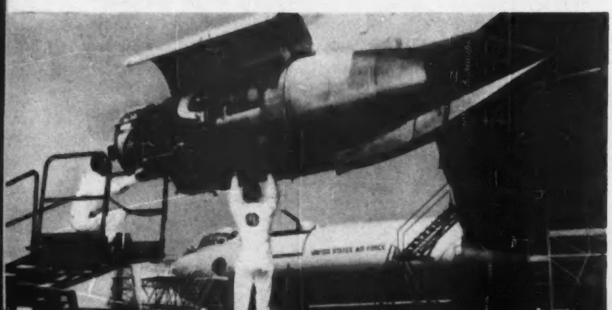


EMERGENCY WORK is handled in your own plant or in a G-E Service Shop. Repairs on this Cleveland plant's 5000-kva transformer were made in six hours at night with no production loss.

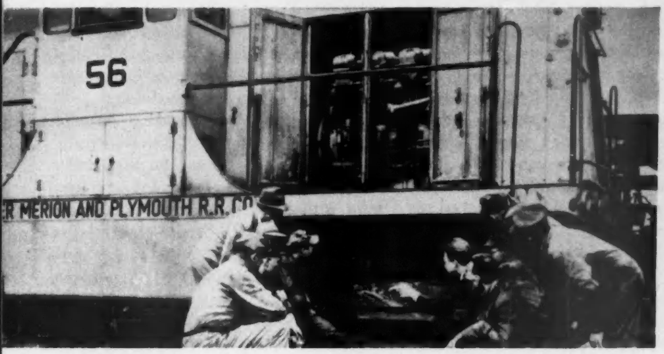


KEEP 'EM SAILING service cuts idle port time with day-and-night work on emergency repairs. Ships keep closer schedules, boost earnings. Here, a propulsion gear is being installed in a modern tanker.

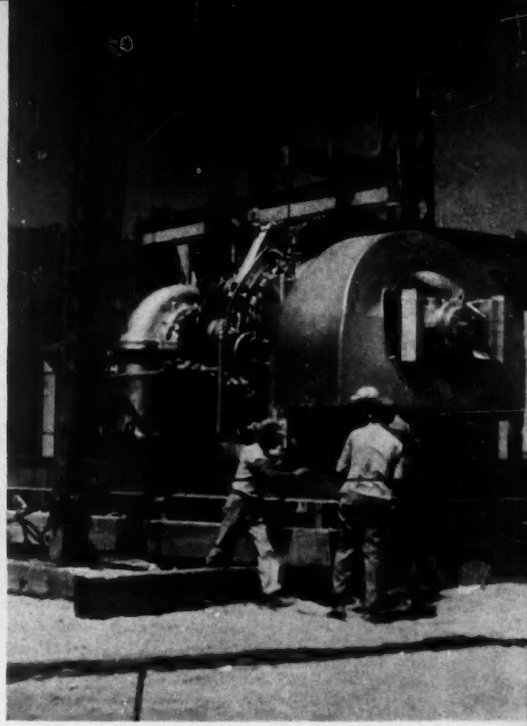
AIRCRAFT MODIFICATION for defense uses four G-E service centers, which work on aircraft gas turbines, turbosuperchargers and fire control. Here G-E technicians check a J47 jet engine.



START-UPS of complex system-engineered equipment are guided by G-E service engineers to assure successful operation. At U. S. Steel's new Fairless Works, G-E engineer W. E. Miller (left) discusses 79½ mph cold-mill drive.



PERSONNEL TRAINING—another G-E engineering service—instructs your men on operating and maintaining large apparatus. Here G-E engineer E. J. Grassie explains locomotive maintenance practice on 44-ton diesel-electric.



SUPERVISION OF INSTALLATION by G-E service engineers assures proper start-up of this gas turbine—one of 28 units for gas-pipeline pumping in the Southwest.

guard your equipment investment

G-E services on installation, maintenance, and repair help assure top performance of your electric apparatus

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672-4C

G-E ENGINEERS William M. Denny (left), manager, and Thornton W. Howard, of the Service Engineering Department, inspect progress made during the installation of a turbine-generator for an Eastern electric utility.

Engineering Leadership gives you better electrical systems from—

GENERAL ELECTRIC

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

By H. H. HENLINE

The American Institute of Electrical Engineers was organized in 1884 as a membership society of electrical engineers interested in encouraging electrical developments and applications. Dr. Nathaniel S. Keith, who was educated as a chemist and practiced as an electrometallurgical engineer, issued a call for a preliminary meeting to be held on April 15, 1884. The plan and scope considered at that meeting was enthusiastically endorsed, and plans were made for a subsequent meeting.

Early Organization

The call for the organization meeting, held May 13, 1884, was answered by many leaders in the new field of electrical engineering including: Edward Weston, Elihu Thomson, C. O. Mailloux, T. C. Martin, and Edwin J. Houston, all of whom later became presidents of the Institute, and Thomas A. Edison, D. Van Nostrand, and Stephen D. Field. At this meeting the name of the society and permanent rules were adopted, and officers were elected.

The first president was Dr. Norvin Green, a physician, then president of the Western Union Telegraph Company. Among the six vice presidents were Alexander Graham Bell and Thomas A. Edison. Dr. Keith was elected secretary. Among the 71 individuals definitely known to have been charter members of the Institute, telephone and telegraph engineers were prominent. Others were employed by electric light and electrical manufacturing companies. Six were professors, two of whom later became presidents of the Institute. Several, including Edison, were inventors. Seven were presidents of companies, four were vice presidents, five were publishers and editors, 17 called themselves electricians, and 10 used the designation electrical engineer.

For many years, the objectives of the Institute have been stated in its constitution as "the advancement of the theory and practice of electrical engineering and of the allied arts and sciences, and the maintenance of a high professional standing among its members." The late J. Allen Johnson, president from 1933 to 1934, paraphrased these goals as "1) To promote better electrical engineering," and "2) To make better electrical engineers." Another president, Dr. John B. Whitehead, 1934 to 1935, said, "If I were asked to name the two grounds upon which the present strength of the Institute exists, I would place first the record of progress as found in its printed pages, and second the power that its meetings and publications have of attracting aspiring young men and maintaining their allegiance."

First Technical Meeting

The first technical meeting was held in Philadelphia, in October 1884, in connection with an International Electrical Exhibition. The first paper presented at the meeting became the first paper in Volume I of the *Transactions*, entitled "Notes on Phenomena in Incandescent Lamps," by Professor Edwin J. Houston.

This presentation treated the fundamentals which led to the development of radio, radar, television, and industrial applications of electronics. It thus established an early record of the interest among the members in a wide range of fundamental scientific developments.

Building and Library

In 1885, a committee of the Institute was authorized to support the steps being taken by the engineering societies in New York to combine in obtaining permanent quarters for their offices, meeting rooms, and libraries. In 1903, when Andrew Carnegie was a guest at a library dinner given by the Institute and spoke of the importance of co-operation among engineers, President Charles F. Scott emphasized the need for a building for the engineering societies.

On the following day Mr. Carnegie invited representatives of the Institute to his home to discuss the need for a building. They were requested to return later with building plans. The outcome of discussions with representatives of three societies was a gift of $1,050,000 for a permanent home for the engineering societies.

The building was completed late in 1906. Soon afterward it was occupied by the American Institute of Mining and Metallurgical Engineers, the American Society of Mechanical Engineers, and the AIEE. The American Society of Civil Engineers came into the building in 1917, following the addition of three stories.

The Latimer-Clarke collection of some 7000 books, pamphlets, and manuscripts —including practically all publications in the English language before 1886 on electricity, magnetism, and related subjects—was presented to the Institute by Dr. Schuyler Skaats Wheeler in 1901.

In 1913, the libraries of the mechanical, mining, and electrical engineers were combined to form the Engineering Societies Library. The ASCE library was added in 1917, and a composite card catalog covering the libraries of the four societies was prepared later.

Sections and Branches

Starting in June 1886, monthly meetings of the Institute were held in New York. As a result of rapid growth in the membership in some other cities, a committee was appointed in 1893 to consider a suggestion that provisions be made for meetings in various cities. In November of that year the Board of Directors approved a plan under which meetings might be held in any city upon

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Mr. Henline is Secretary of the American Institute of Electrical Engineers. He has served in this capacity since 1932.

petition of 20 members. Monthly meetings in Chicago were inaugurated in 1894.

Upon becoming president in 1902, Charles F. Scott accepted Secretary Pope's suggestion that special efforts be made to extend the holding of local meetings. His address, "Proposed Developments of the Institute," included such an effective presentation of the advantages of local meetings of members and meetings of students—wherever the numbers and the interest were adequate—that the Board of Directors authorized the establishment of the two types of local organizations now known as Sections and Student Branches.

The new plan was accepted enthusiastically by members and students. On May 1, 1902, the membership was 1549, and the Institute was the smallest of the four leading engineering societies. During the next four years the membership grew so rapidly that the AIEE became the largest of the four societies, attaining a membership of 3870 on May 1, 1906. About 10 years later it was passed by one of the other societies. Since 1937, it has been the largest.

A plan for the enrollment of Students in the Institute was adopted in 1903, and many further provisions have been adopted from time to time for the purpose of bringing the Students actively into Institute affairs, with the many advantages to themselves that normally come from active participation in technical society work.

Throughout most of the period since 1902 the numbers of Sections and Student Branches increased steadily, until now there are 96 Sections, more than 50 Subsections, and 132 Student Branches.

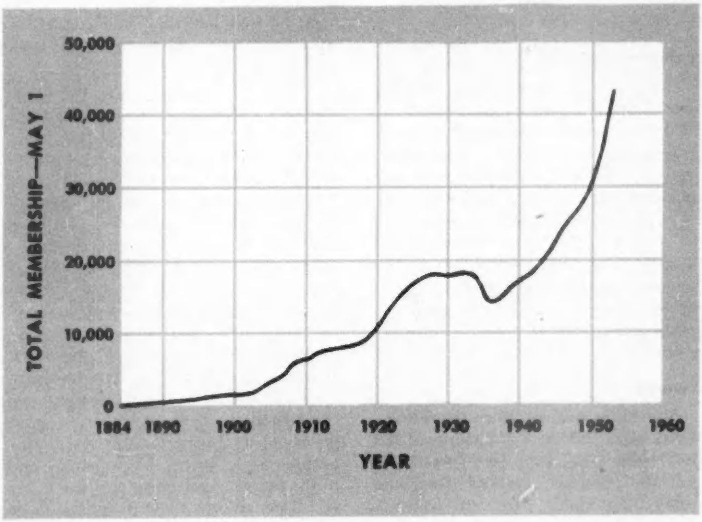
Standards

With the appointment on December 3, 1889, of a committee to formulate and submit for approval a standard wiring table for lighting and power apparatus, the AIEE embarked upon standards activities, which later became one of its major types of work.

The standardization of generators, motors, and transformers was discussed in New York and Chicago in January 1898. The development of a set of rules was favored, and a committee on standards was appointed. The report of the committee was presented and accepted in January 1899. The rules, expanded to cover other types of equipment, were revised frequently.

By 1922, the volume of standards was so extensive that it seemed advisable to abandon the single-volume plan and publish each standard as a separate pamphlet. The work was expanded to include electrical definitions, symbols, and so on; the standards are now issued in more than 50 pamphlets.

ENGINEERING SOCIETIES' Building near Fifth Avenue on 39th Street in New York



MEMBERSHIP CURVE showing growth of the AIEE since the founding of the Institute in 1884 (Student members are not included)

The Institute was one of the founders of the American Standards Association. More than half of the existing AIEE Standards have been approved by it as American Standards.

Progress—1919 to 1952

To a large extent Institute activities have been developed step by step as recommendations were made by Districts, committees, Section delegates, and other groups. The most notable examples of comprehensive studies made for the purpose of introducing more fundamental or far-reaching changes were those made by the Committee on Development, which reported in 1919, and the Committee on Planning and Coordination, which carried out a thorough consideration of technical and nontechnical activities during several years, beginning in 1945.

As results of the recommendations of the Committee on Development, the name of the monthly publication was changed to the *Journal*, the page size was increased, major changes were made in the contents, and a broader advertising policy was adopted; a New York Section was established to take the place of the previous monthly meetings of the Institute; the policy of holding some Institute and Directors' meetings in various localities having Sections was expanded; the division of the country into Districts, with the election of a vice president in each was adopted; the vice presidents were given the duty of visiting Sections; and encouragement was given to the formation of local engineering federations and a national engineering council.

In 1945, the Committee on Planning and Co-ordination was requested to undertake a double project: review the technical activities and the Institute's relations with other engineering organizations, and to recommend any changes in organization or activities which might be needed to enable the AIEE to be sufficiently flexible to take account of progress in the art and provide for rapid development of new fields of interest.

The over-all project of the Committee on Planning and Co-ordination resulted in numerous changes within the Institute, including the establishment of five technical divisions, with a total of 39 technical committees; the establishment of a Committee on Technical Operations through a combination of the Technical Program and Technical Advisory Committees; changes in the Bylaws regarding both general and technical committees; the addition of the Fall General Meeting; and changes in the membership requirements in the Constitution to make the grades more nearly consistent with those recommended by the Engineers Council for Professional Development.

Meetings

After holding an annual meeting for more than 25 years, the AIEE added the Pacific General Meeting in 1910, held in August or September, in the far-western part of the country, or in Western Canada; the Winter General Meeting in 1913, usually held in New York City; and the Fall General Meeting in 1947, held in the Middle West. The present Summer General Meeting continues the series of annual meetings started in 1884.

District Meetings have been held since 1924, frequently three or four per year. They are completely within the control of the District committees unless papers are desired from outside the District. The fundamental plan for such meetings is to have programs largely originating within the District holding the meeting and of special interest to its members.

Special Technical Conferences were inaugurated in 1948, and about eight or nine are held each year. Each is devoted to a specialized subject and has the function of assisting the technical committee in that field in desirable expansions of its activities.

Publications

Starting with annual *Transactions* in 1884 and monthly *Proceedings* in 1887, the Institute passed through several important transitions in publication plans to meet the desires of the members as fully as possible. It changed in 1920 from the *Proceedings* to the *Journal*, at which time the page size was enlarged, and in 1931 it was changed to *Electrical Engineering*. Various changes were made in the types of material published. Since 1947, the range of contents has been broader than before.

In connection with the development of the five technical divisions, publication of the *Transactions* papers in three bimonthly parts was started in July 1952. Papers in the Communication Division and the Science and Electronics Division are included in one part, and those in the General Applications Division and the Industry Division in another. The third will include papers in the Power Division. Members may receive one of the parts without charge, and they can subscribe to the others. The annual *Transactions* will be published in three parts corresponding to the bimonthly parts.

Membership Grades

Two grades of membership, Member and Associate, were established in 1884. The grade of Fellow, with requirements above those of Member, was added in 1912. Through extensive amendments to the Constitution in 1951, the grade of Affiliate was added for persons who are not employed directly in engineering, the title of the Associate grade was changed to Associate Member, and the grade of Fellow was restricted solely to transfers by invitation of the Board of Directors.

Awards

The AIEE has awarded the Edison Medal since 1909, the Lamme Medal since 1928, prizes for papers since 1927, and the Charles LeGeyt Fortescue Fellowships since 1940. It has co-operated with other engineering societies for many years in the joint awards—Alfred Nobel Prize, Washington Award, Hoover Medal, and John Fritz Medal. It co-operates with other engineering societies and the Iowa State College in the award of the Marston Medal.

Joint Activities

In addition to its participation in the efforts which resulted in the provision of a building for the engineering societies, the AIEE has been among the founders of and an active participant in many joint organizations—Engineering Foundation, American Engineering Council, American Standards Association, Engineers Council for Professional Development, Engineers Joint Council, and others. It has representatives on many other organizations.

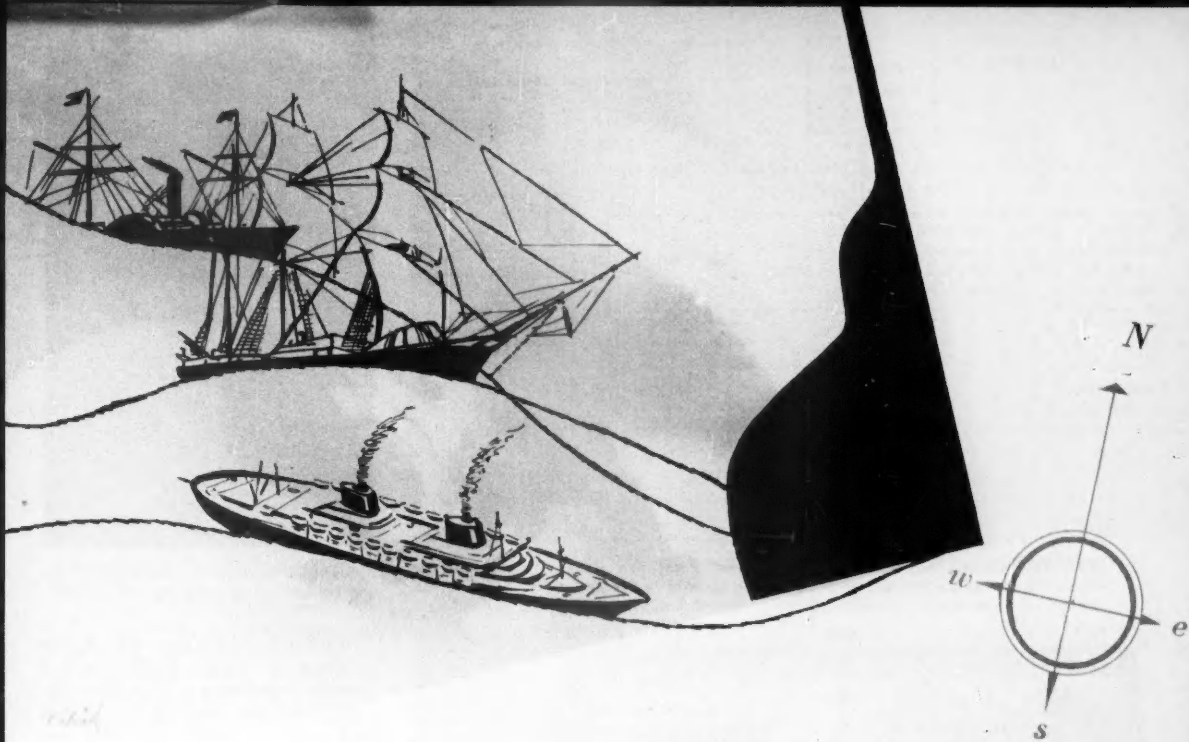
Contributions to Progress

The contributions of the AIEE to the advancement of electrical engineering and the engineering profession have appeared in many forms, some tangible and others quite intangible but nevertheless important. Undoubtedly, its contributions to the development of the personal qualifications of its Student members and older members should be placed at the head of the list.

Acquaintanceship with the leaders in the field and the inspiration and enthusiasm derived from contacts with them are most important factors in the development of leaders. Institute meetings, Section meetings, and committee work bring many opportunities for such contacts.

AIEE activities in general encourage technical developments in important divisions of the field; meetings provide opportunities for presentation of papers and discussions; the publications constitute permanent records of outstanding developments; and the standards are of incalculable value to industry.

The Institute is primarily a technical organization which encourages developments in the entire field of electrical engineering, with the accompanying development of leadership among its members. It responds promptly to new technical needs, as well as to new interests among the members. It is, necessarily, what its members make it, and its contributions to technical developments and to the entire engineering profession are the direct results of contributions made by many members through its organized activities. Ω



Steering Ships

By A. D. HAMMES

When the *United States* set a new Atlantic crossing record last July, she regained a distinction that America once held unchallenged for many years.

Yankee clipper ships of old had repeatedly made and broken transatlantic records. Oddly enough, they did it less for glory than for cargoes that went to the fastest ships. Their disappearance from the scene marked the beginning of the end for another form of human endeavor—direct manual steering of ships.

You can easily appreciate the physical effort involved when steering wheels were coupled directly to rudders by ropes or cables. In heavy weather the effort was particularly strenuous. And as ships became larger, the effort became greater than man—or men—could exert directly.

Some form of steering engine was inevitable. The first to come was operated by steam; later ones by hydraulic and electric means.

Steering Engines

Because of relatively restricted rudder motion (±35 degrees on sea-going vessels; ±45 degrees on Great Lakes' ships), steering engines take specialized forms.

The most common type utilizes one or more hydraulic rams—a device that essentially consists of a two-directional oil-operated piston with rods projecting from either end of its enclosing cylinder. Linear motion of the piston is converted to the rudder's rotary motion by suitable linkage between piston rods and rudder posts. Actual effort required to move the piston, and rudder, is supplied indirectly through an electric motor running at constant speed. The motor drives an oil pump (capable of pumping oil in either direction) that's controlled through a differential mechanism.

Helm, or rudder, order from the steering station, fed into one side of the differential, determines the direction of oil pumped to the ram and ultimately controls the rudder. And rudder position, fed back to the other side of the differential, recenters the pump when the rudder reaches its desired position. In this way the rudder's position is made proportional to the controlling shaft, or "stroke," position.

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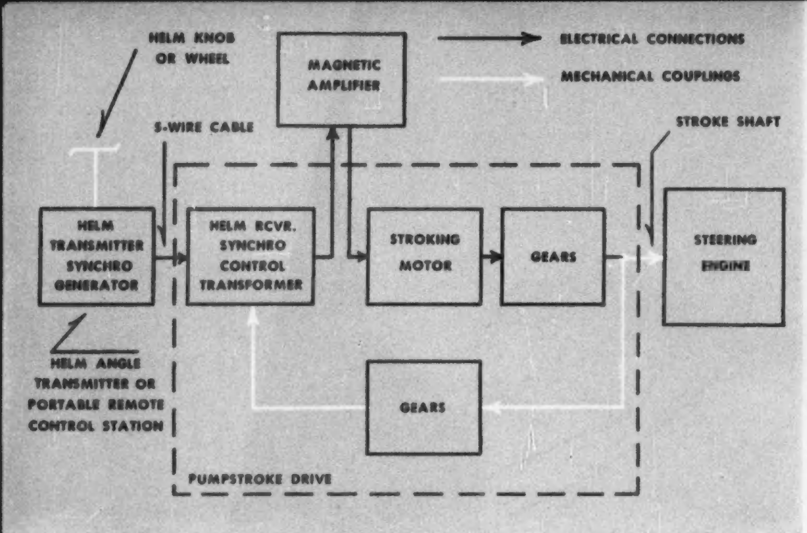
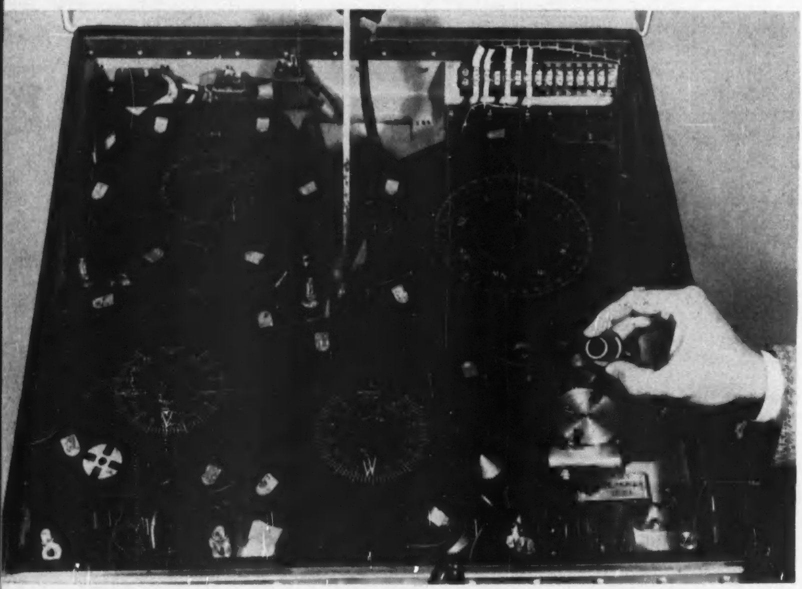
Mr. Hammes is a sales engineer in the Aeronautic and Ordnance Systems Division in General Electric at Schenectady. He has commercial responsibility for system controls for marine propulsion, steering, and auxiliary machinery, and co-ordinates the Company's hydraulic-control-system business.



FIVE-WIRE CABLE that transmits helm order information is the only connection between the control station and steering engine located in the stern of the ship

CONTROL equipment is housed in steering console being examined by author



FOUR DIALS of the steering console tell the helmsman the complete story at any instant. The dial at upper left continuously indicates the ship's actual heading. Course-setter dial for automatic steering at upper right is to put the ship to a desired course; the helmsman sets the heading by turning a knob (removed) at lower right. For manual steering the helmsman uses the handwheel, the heading indicated by the dial at lower left being followed by the rudder. A synchronizing device keeps the autopilot always set to the ship's heading so that it can be engaged at any time without danger of putting the ship into a sweeping turn. The dial at lower left indicates rudder limits for controlled maneuvering, and also the helm angle. Maximum rudder angle that the autopilot will call for is set by the helmsman, and automatic turns are then made by adjusting the course-setter dial. A portable steering stand also provides hand-steering from other points in the ship, via plug-in outlets

It would be logical for you to assume at this point that all the horsework of steering is eliminated. This isn't strictly true. For, regardless of the type of engine used, it must be controlled from the steering station.

Control Problem

The three approaches commonly used to control steering engines are mechanical, hydraulic, and electric.

Mechanical control is exerted through cables or a rotating shaft. It's the simplest but least efficient system. For, the helmsman has to supply the effort to control the steering engine and make up for mechanical losses as well. Installation is troublesome, and the system isn't suited for control over distances of 50 feet.

Some of the major disadvantages of the purely mechanical approach are overcome by a hydraulic control, called a "telemotor system." Such a system is in the nature of two pumps, one a transmitter and the other a receiver, interconnected with pipes. By manually turning a steering wheel geared to the transmitter, the helmsman pumps a fixed quantity of oil per revolution to the receiver. It in turn repeats helm order at the steering engine.

While a good telemotor system has low mechanical losses over distances on the order of 100 feet or more, the helmsman still exerts the effort to control the steering engine. Installation is complicated by lengthy runs of piping. If high temperatures cause appreciable expansion of the oil, the system may become sluggish or lock completely.

You can conclude, then, that the answer to the disadvantages of the mechanical and hydraulic systems is an electric one, and rightly so. The two main types of electric controls are the power synchro and the pilot motor.

A power synchro, or "synchro tie," is used on many present-day naval vessels. It makes use of selsyn-type machines (derived from the expression "self synchronous") capable of controlling the steering engine. A selsyn system is actually a generator and motor combination with their stator windings connected—when the rotor of the generator, or transmitter, is turned, the rotor of the remotely located motor, or receiver, duplicates its movement.

Although less than in the other systems, here again the helmsman supplies some effort. He must turn the rotor of the generator, or transmitter, to steer the ship. Nevertheless, the efficiency of the power synchro system is high, as is its reliability. Installation is relatively simple compared to mechanical and telemotor systems.

A pilot motor system, as you'll imply from its name, makes use of a remotely operated motor that performs the work of controlling the steering engine. It has the major advantage of relieving the helmsman of practically all physical effort. Until recently, however, pilot motors were themselves controlled by relatively crude means, and for this reason were not widely used. (A "trolley-car" type of controller was usually employed. It had a finite number of steps, and so the rudder couldn't be controlled continuously but only in a series of increments. Other kinds of controls using relays and sliding contacts were not dependable.)

So far you've been acquainted with steering systems in terms of the human helmsman. Let's turn now to the automatic helmsman, or autopilot.

Automatic Steering

Automatically steering a predetermined course dates back at least as far as the early twenties when the first commercial autopilots became available. By modern standards they were crude. Yet, these early pilots turned in creditable performance. Designed only to provide automatic course-holding, they outperformed the human helmsman at his task. And though accurate measurement was difficult with instruments then available, they apparently approached the steering accuracy achieved by more modern pilots.

Autopilots developed during and since the second World War have incorporated servomechanisms and components developed through nearly three decades. (For our purposes you can think of a servomechanism as a feedback system in which the difference between input and output is used to control the output, making it proportional to the input.) Much knowledge is borrowed from related fields. We now have available much data on the steering and turning properties of ships, which—coupled with modern servomechanism theory—permit an accurate appraisal of proposed steering systems.

With the help of laboratory setups such information enables us to simulate actual conditions for development purposes, and to do away with the old shipboard cut-and-try methods. For instance, a proposed steering system that passes basic analytical tests is built up in "breadboard," or model, form and operated into a ship simulator—a device that duplicates a ship's movements. In this way a close approximation to actual performance is obtained, and final development is carried out in the laboratory.

Using these modern laboratory techniques we've developed advanced steering systems for application to commercial and naval craft. Some of their features are still classified, but enough can be said to give you a pretty good idea of how they work.

Steering by Hand

From any number of preselected steering stations the *hand electric* system provides rudder control. Its operational advantage over other systems is the reduction of steering effort required, plus its accuracy and reliability. In fact, the effort is so small that a friction brake is supplied to put some "feel" into it. The steering wheel (or knob, if used) can be geared to call for 35 degrees rudder for as little as half a turn. With the horsework eliminated the helmsman needn't be relieved at such frequent intervals under rough sea conditions—common with older types of steering. Operational tests confirm that it enables the average man to do a better steering job, too.

In essence the system consists of a remotely controlled servomechanism that positions the steering engine stroke, or control, shaft in accordance with helm order. You'll note from the block diagram on the opposite page that helm order is transmitted by a selsyn generator (to which the steering wheel or knob is geared) over a five-wire cable to the steering-gear room. Here the helm receiver—a "matching" control transformer—produces an electrical error signal proportional to helm order. This signal is magnetically amplified and controls a stroking motor that determines the amount and direction of rudder called for by the steering engine.

As the motor strokes the steering engine, it also turns the rotor of the helm receiver so that the error signal is reduced to zero precisely when the correct amount of rudder is called for. Thereupon it stops running and holds that position until a new helm order is initiated.

Connecting wires required between a given control point and the steering-gear room being few, the use of a portable steering stand is facilitated. A helm angle transmitter and a rudder angle repeater, the equipment needed, can be neatly housed in a small case. Then it's only necessary to provide plug-in outlets at any desired steering station.

Steering by Pilot

To go one step further an elementary course-holding feature, *basic autosteering*, is added to the system. This is done through use of a differential selsyn generator—one that produces a signal proportional to the difference between its own rotor position and that of an input generator.

A gyrocompass—a precision north-seeking gyroscope—provides a reference axis and the excitation for the differential generator, and it in turn signals the helm receiver for rudder proportional to course error. (The rotor of a special-mounted three-phase motor provides the gyroscope's mass. Once set in motion it resists angular displacement.) The helm receiver then controls the rudder position exactly as before. Only there is this difference: the gyro is controlling the rudder through the differential generator—the human helmsman isn't necessary. An emergency

HERE'S THE BASIS OF ADVANCED AUTOMATIC STEERING

$$D = (K_\theta \Theta + K_r p \Theta + \frac{K_T \Theta}{p})$$

where D = total error or director signal to the automatic pilot

Θ = heading error

$p = \frac{d}{dt}, \frac{1}{p} = \int dt$

K_θ = gyro gradient (amount of error signal per unit heading error)

K_r = rate gradient (amount of error signal per unit rate of change of error)

K_T = trim gradient (amount of signal per unit time integral of heading error)

This equation states that the director signal D is a function of heading error, its rate of change, and its time integral.

Ordinarily K_θ is equal to unity but the automatic helm servomechanism is commonly adjusted so that its effective value is two. That is, one degree of error signal calls for two degrees of rudder, or a rudder ratio of 2:1. Although readily adjustable from less than unity to infinity, the practical rudder ratio is from 1:1 through 4:1.

The value of K_r is dependent upon the hull's inherent dynamic stability, the ship's turning characteristics, and—to some degree—the automatic trim gradient.

Relatively small, the trim gradient K_T has little or no effect on D except during steady upsetting conditions.

override switch permits instant return to manual control.

One great advantage of this system is that you get automatic steering with few additional components and little extra cost. Where more than simple course-holding is required, however, a somewhat more elaborate but infinitely more flexible system is available.

Advanced Steering

The more elaborate *advanced automatic* system utilizes a modified helm transmitter such that the helm angle specified by it is proportional to heading error and rate of change of this error.

Affording rudder "anticipation" is the function of the rate of change signal. It prevents overshooting the course or oscillation of the ship. (Strictly speaking, pilots built to date hold heading but not true course. That is, the pilot will keep the ship pointed in a given direction but takes no account of lateral drift. While one can be built to correct this, navigation techniques permit direct compensation.)

Other features of the advanced system are—

Controlled Maneuvering—This is obtained through use of adjustable rudder limits. Maximum rudder angle that the autopilot will call for is set by the helmsman. Automatic turns are made simply by adjusting the course-setter dial of the steering console to the desired course (see photos page 38). Turns of known tactical diameter are then made by the ship.

At the critical point, determined by remaining course error and rate of turn, the rudder is released and sufficient reverse rudder called for to "meet the ship." (The idea is to stop its turning motion without unduly overshooting the course.) A small overshoot however is desirable because it reduces time necessary to make the turn. That is, a "deadbeat" system takes longer to reach equilibrium than one slightly under damped—if the ship is turning too fast, rudder is released early; if too slow, later. This way the autopilot compensates for variations in rate of turn resulting from wind, sea, or other conditions.

Automatic Trim—Trim rudder, in case you're not familiar with the term, is that amount of rudder "held in" to compensate for turning moments caused by *steady* upsetting conditions. These may be wind, current, hull, or screw damage, or a combination of them.

In manual steering the helmsman carries sufficient standing rudder to make up for extraneous turning moments, thereby allowing the ship to maintain her heading. However, an autopilot calling for rudder proportional to course error and its rate of change will, of necessity, allow the ship to "crab" if such upsetting conditions exist. Put another way, the ship will turn under the influence of the upsetting torque until the heading error becomes large enough to call for sufficient rudder to reduce the *net* torque to zero.

An automatic trim control is obviously the answer to crabbing. There are several ways of accomplishing it. Each method is basically the same: the pilot is caused to call for rudder in proportion to the time-integral of heading error, in addition to its other functions. Value of the integral steadily increases until the corrective rudder called for reduces the error to zero. Integrating action then ceases.

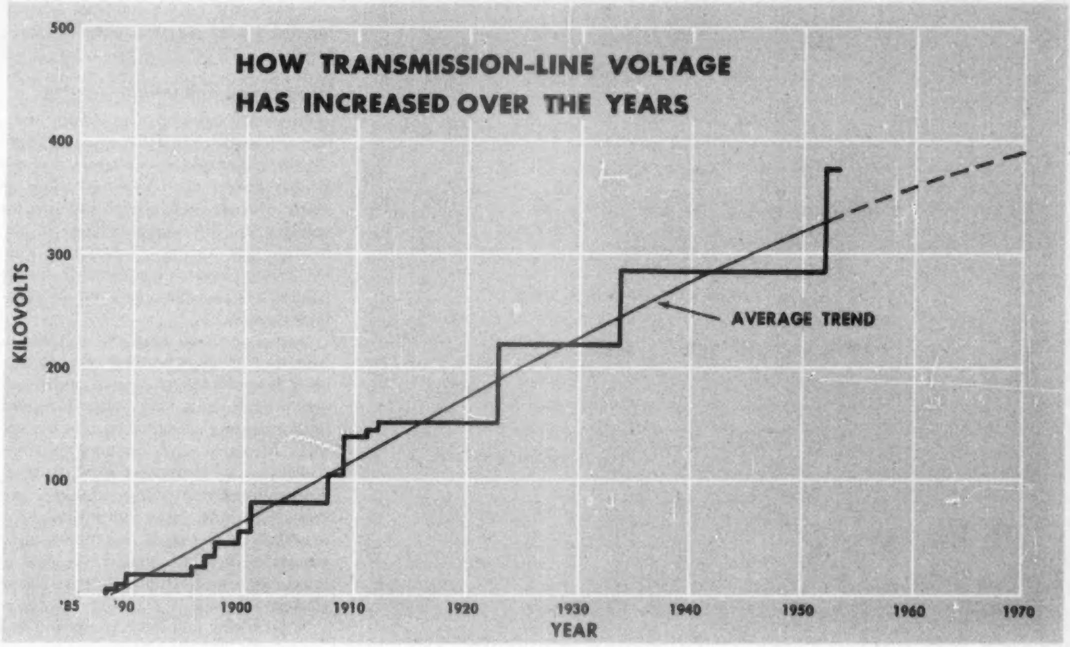
The automatic trim control, or error integrator, therefore allows the ship to maintain her heading in the face of steady upsetting conditions. (The complete equation for advanced automatic steering appears on this page.)

Weather Adjustment—Yaw is the ship's temporary deviation from her course when struck by a heavy sea or other *temporary* upsetting condition. In rough weather the rudder isn't able to prevent yawing. For this reason it's desirable to restrict rudder motion and allow the ship to yaw more or less freely, thereby conserving power and reducing structural strain. The weather adjustment does this by decreasing pilot gain—experience indicates that restricting rudder motion to 25 percent of full gain value seldom increases yawing more than 25 to 30 percent.

Automatic Synchronization—This device keeps the autopilot always set to the ship's instantaneous heading while under manual control. It makes possible the engagement of the autopilot any time without danger that the ship will be put into a sweeping turn to some heading different than the one being steered.

The advanced autosteering system can, of course, be supplied with any desired combination of the foregoing features. For instance, you might want accurate steering in the face of running seas and shifting winds, but not controlled maneuvering. The rudder limits would accordingly be omitted, and the automatic trim retained.

You can see, then, that steering ships isn't what it used to be. Although the systems described represent the latest word in ship steering, they're not the last word. Already a new manual control, lower in cost and superior in performance, has been demonstrated in our laboratory. And typical of progress being made, automatic steering can be supplied for this new control at a total cost less than that of the first hand electric system alone. Ω



WITH THE AVERAGE TREND IN TRANSMISSION VOLTAGE POINTING EVER UPWARD THROUGHOUT THE YEARS, IT'S IMPORTANT TO ASK . . .

What's Ahead in High-voltage Transmission?

By S. B. CRARY

How do higher voltages help electric utilities reduce the cost of transmitting power? What part does "superposing" and "interconnection" play in making a transmission system more economical?

With more than one-half billion dollars being spent annually in the United States for power transmission, it is important to know the answers to these questions. How the transmission system is built today will determine how efficiently the over-all system will operate tomorrow.

Circuits have increased to the point where there are now 280,000 miles of transmission lines in the U. S. Transmission voltages have made great progress (curve, above) since the earliest power cable—a 220-volt Edison tube consisting of three copper rods in an iron pipe, insulated with jute and asphalt—went into operation in 1879. Not only has the voltage gone up, but similar progress has been made in the current loading.

At the present time a pattern is evolving in the design of transmission systems—a pattern that differs quite a bit from previous concepts.

Now under construction in this country are the first links of a new 330-kv transmission system that will have a conductor capable of carrying a load approaching one million kilowatts per circuit.

Sweden is already operating a 380-kv 600-mile line using dual conductors per phase. With the use of series capacitors, it is expected to carry a load as high as 850,000 kw on a single circuit.

Indicative of this new philosophy of using high circuit loadings is a system in British Columbia where the Aluminum Company of Canada is building 288-kv transmission lines that will carry 850,000 kw per circuit with a 2.2-inch diameter ACSR phase conductor. In an emergency this conductor may be required to carry even greater loadings. Other systems are planned for 345 kv and 400 kv.

These new systems point the way to the future possibilities of high-circuit loadings which is the most important and significant method for keeping transmission costs to a minimum.

(Incidentally, these accomplishments in the highest system voltages are also significant of the trend that is going on at the lower-voltage levels.)

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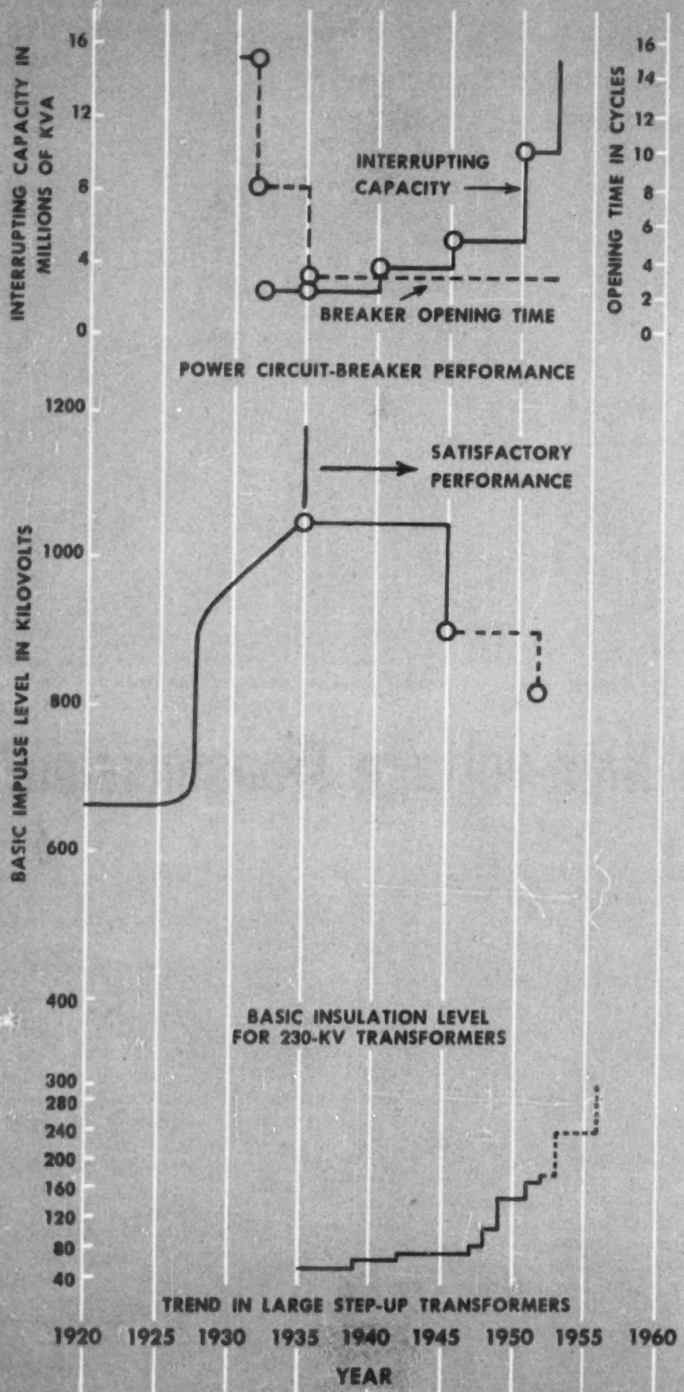
With General Electric for 25 years, Mr. Crary is Manager, Analytical Engineering Department of the Apparatus Sales Division at Schenectady. An AIEE Fellow, he is chairman of the Institute's Committee on Transmission and Distribution. Last spring he again attended the biennial CIGRE Conference in Paris.



The over-all trend is definitely to more heavily loaded circuits at *all* voltage levels.

Superposing and Interconnecting

Electric utilities have a problem when they are required to deliver larger blocks of power through or over areas that are already electrically developed. This is often solved by superposing higher voltages on the lower voltage of the existing systems—an evolutionary step in system design. (Superseded lower-voltage systems may be used for sub-transmission.)

Interconnection between systems in adjoining areas is another step that is being taken by the utilities to get further operating benefits. This procedure also helps maintain a flexible system to cope with increases and changes in load which may be augmented by shifts from a peacetime to a wartime economy, and vice versa. An interconnection to a neighboring system at a common high-voltage level, when justified, is ideal in providing a tie having high interchange capacity.

Superposing and interconnecting at a higher-voltage level has many economies such as reducing the necessary reserved capacity, increasing the load diversity, and decreasing the losses. Assisted by network analyzer studies, the costs of the various alternative methods can be compared, and the most economical plan determined.

Economics of High Voltage

The economics of high voltage is determined chiefly by the following principle: *The cost per kilowatt of tower-line capability goes down with increasing voltage, whereas the cost per transformer kva increases with increasing voltage, and decreases with increasing transformer-bank capacity.*

Accordingly, higher voltage becomes more economical when it is used to transmit a large block of power using large transformers at the step-up and step-down terminals. And higher voltage also becomes more favorable as the transmission-line distance increases.

Today, with modern concepts of circuit loading, higher voltages can be justified at much shorter distances than was previously considered economical. For example, depending upon local conditions, it may be entirely economical with a voltage such as 330 kv to transmit 500,000 kw per three-phase circuit a distance of 50 to 100 miles. For a double-circuit tower, this would be one million kilowatts.

Superposing of a higher voltage, at least twice as high as the existing voltage, generally becomes desirable at the time when it becomes necessary to keep the number of paralleled lower-voltage circuits to no more than four. This is a rule-of-thumb that has been developed from specific studies. Also, the more rapid the load growth, the more quickly the higher voltage is justified. The higher voltage may be used in some cases to carry a large block of power into a new area, in which case two new circuits may become necessary to assure a proper degree of reliability.

D-c transmission for overhead lines has been considered as a possibility, but as yet it does not compete with alternating current even for straightaway distances as long as 600 miles. For underground or submarine transmission, direct current does not appear to be competitive with alternating current, except at distances greater than about 60 miles.

Concepts and Tools Available

Increased loadings of transmission circuits are not of much use unless equipment is available to handle them.

Some of the most important equipment developments follow, beginning with those in the field of . . . .

Switchgear—The trend in circuit breakers toward higher interrupting capacity, quicker fault clearing and reclosing, and higher ampere continuous circuit rating has made it possible to realize system designs with high circuit loadings.

This trend has also made it feasible to solidly interconnect the high-voltage system. This is of major importance because the solidly interconnected system is the design pattern of the future at practically all voltage levels.

Higher-voltage systems now being planned—330 kv, for example—will use circuit breakers of 15-million-kva interrupting capacity with three-cycle opening time, 20-cycle reclosing time, and 1600-amp continuous current.

The curve at the top of the opposite page shows the increase in interrupting capacity and the decrease in breaker opening time over the years. Those are the two most important performance characteristics of circuit breakers.

Cable—Increased loadings for high-voltage cable has gone up along with the loading of overhead circuits. Today loadings up to 300,000 kva are possible at 138 kv, and at 230 kv the loadings may be increased to 370,000 to 405,000 kva for oil-filled cable in ducts. With the increasing cost of right-of-way, and the prohibitive cost of obtaining right-of-way for overhead lines near large metropolitan areas, more and more high-voltage cable will be used. High circuit loadings for cable, as for overhead lines, are best realized in a solidly interconnected high-voltage system.

Reduced Insulation—Along with the increased circuit loadings of cable and overhead lines, several supplementary trends have developed that will help cut the cost of power transmission.

One of these is the practice of using reduced line insulation. By doing this, you can take full advantage of modern methods of protecting and shielding the overhead line from lightning, as well as getting the full benefit of high-speed circuit-breaker reclosing that greatly minimizes faults due to lightning, and all other faults of a temporary nature. A recent survey indicates that for voltages of 100 kv and higher, 90 percent of the faults were temporary and capable of immediate or quick reclosing.

Reduced insulation of terminal equipment has also made great strides in the last few years. Today the majority of high-voltage transformers (115 kv and higher) use reduced insulation, as well as grounded neutral insulation. Circuit breakers are also being built with reduced insulation to ground at the 230-kv level and higher, because practically all systems in the higher-voltage classification are solidly grounded. The middle curve on the opposite page shows the trend in transformer insulation level for 230-kv equipment—a trend that is typical for most voltage ratings.

Some unsatisfactory experiences with high-voltage transformers in the 1920's resulted in an increase in the insulation level. But after 1935 satisfactory experience was attained, largely because of better co-ordination with the lightning-arrester protective levels. As a result the insulation levels of transformers were successfully reduced to 900 kv at 230-kv circuit voltage on systems with grounded neutral. Such excellent operating results were obtained that this basic impulse level (BIL) became practically universal for such applications. More recently, some installations have been made with insulation levels down to 825 BIL at 230-kv operating voltage, a step that appears to be entirely rational considering continued progress in the design of lightning arresters, circuit breakers, and other related system apparatus.

Transformers—The major investment items of high-voltage transmission are the transmission lines and the transformers at the terminals. At the higher-voltage levels, and for distances less than 100 miles, the transformer cost

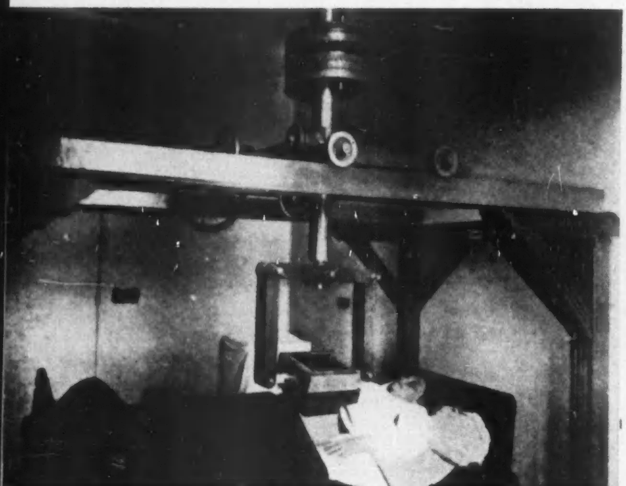
(Concluded on page 60)

INTRODUCTION

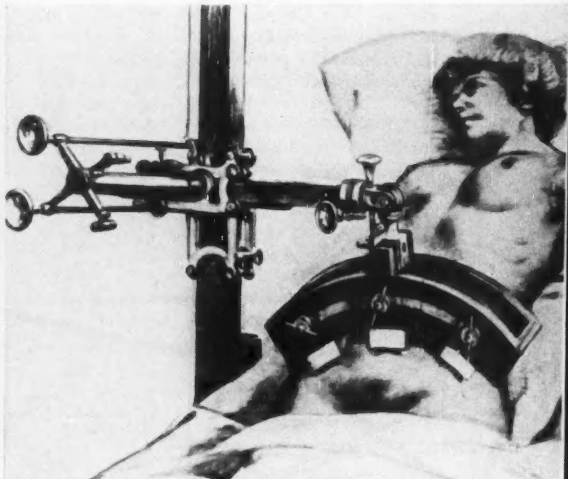
Late in 1949 the Medical Division of the Oak Ridge Institute of Nuclear Studies and the M. D. Anderson Hospital for Cancer Research in Houston began a joint program for the design, construction, and experimental testing of a large Cobalt-60 teletherapy unit. A portion of the cost of the project was supplied by the Damon Runyon Cancer Fund. These institutions entered into a contract with the X-Ray Department of General Electric in 1951 calling for construction of the unit.

The completed Cobalt-60 irradiator (left) is installed at the Oak Ridge Institute of Nuclear Studies. It is loaded with a 200-curie Cobalt-60 source, and studies of shielding, radium-beam characteristics, depth dose, and biological effects are underway. When these are completed, the unit will be reloaded with a 1000-curie (effective) source from Canada's Chalk River atomic pile. The equipment will then be transferred to the M. D. Anderson Hospital for Cancer Research—Editors

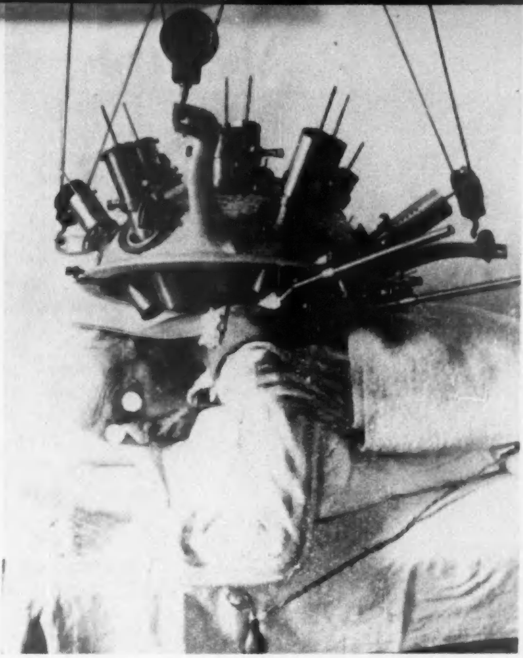
Cobalt-60 Irradiator —



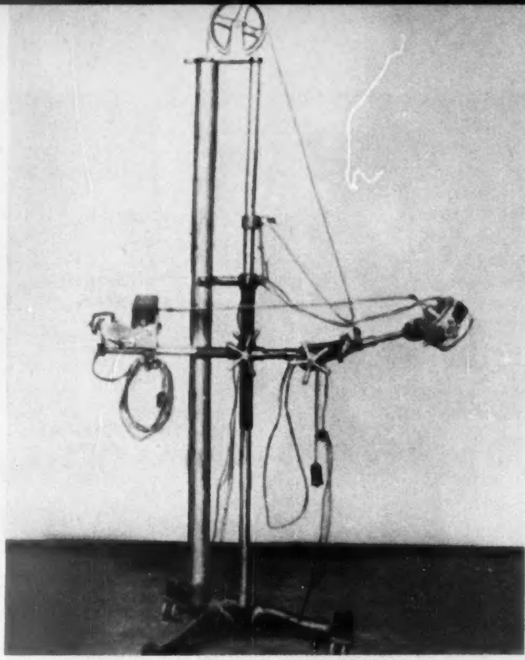
REGAUD-FERROUX This early French design used a thick lead container to shield a radium source of four grams



MALLET Another French design utilized radium sources in form of needles inserted into the diseased tissue



SLUYS-KESSLER Radium sources were focused to a common center and kept at six to eight centimeters from the skin



STENSTROM Multiple sources of radon, the radioactive gas formed from radium, were used in this early American unit

New Tool for Medical Research

By E. DALE TROUT and JOHN VLACH

Completion of the Cobalt-60 irradiator marks the beginning of an era to which medical researchers look hopefully forward. Their need is for a simple low-cost source of high-energy radiation. Although this hope hasn't been fully realized, the future looks bright enough to justify the exploratory steps that always precede wide utilization of a new process or material.

Pile-produced isotopes for teletherapy must, among other things, emit gamma radiation and have a half-life longer than 150 days. Radioactive Cobalt-60 emits gamma radiation, has a half-life of 5.3 years, and is obtained from the waste by-products of plutonium production. A 1000-curie Cobalt-60 source should produce a radiation intensity about equal to 1500 grams of radium (a curie is a measure of radiation intensity). It should also be comparable to a three-million electron-volt x-ray machine in the matter of depth dosage to the patient (gamma rays have much shorter wave lengths than x-rays and are therefore more penetrating). The 1000-curie source is presently quoted as costing from \$15,000 to \$18,000 whereas one gram of radium costs better than \$20,000.

Looking Back

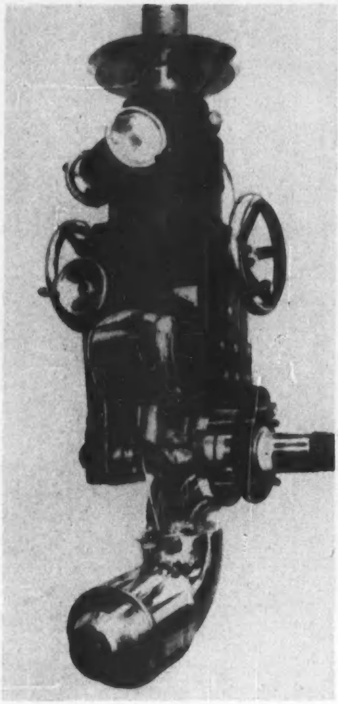
Most of the so-called new things are founded upon past experience and are usually refinements of previously used methods. Such was the condition in setting out to design the Cobalt-60 irradiator. The source was new; some of the materials and mechanisms hadn't been used for this application before but the really basic ideas were explored over a period of about 30 years.

Therefore, a brief review of events leading to its design would seem the logical starting point.

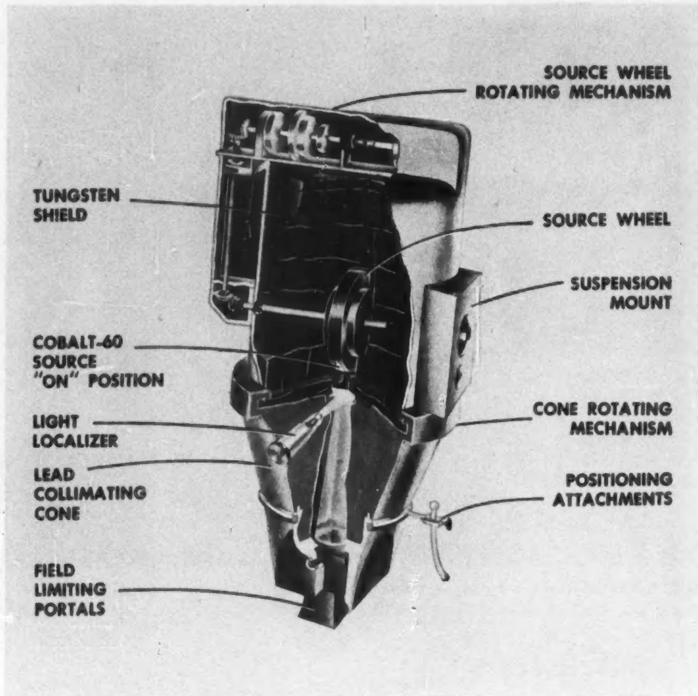
A young Polish student, Mary Sklodowska, arrived in Paris in 1891. Four years later she married a French physicist named Pierre Curie, already known for his remarkable work. As the subject of her doctorate thesis, she made an investigation to determine whether there were other elements in existence emitting rays analogous to those of uranium. She found but one, thorium, also a heavy element and almost a neighbor of uranium in the periodic table. Further research in collaboration with her husband brought about their discovery of a new radioactive element, polonium, in 1898. Later that year they announced the discovery of radium.

Radium Therapy

Radium therapy dates from the time immediately following the discovery of radium by the Curies. The general idea is to selectively destroy diseased cells. In doing so, advantage is taken of the fact that these are more "radiosensitive" than normal cells.



GRIMMET British teleradium unit was most advanced of early designs



COBALT-60 UNIT combines good shielding for the operator with simplified control of gamma-ray beam. Treatment cones accommodate various field sizes

The heavy atoms of radium are subject to spontaneous disintegration. Accompanying this atomic evolution is an emission called "radioactive" that consists of alpha, beta, and gamma rays. To make use of the emission, radium has been used: 1) at a distance of a few centimeters or more away from the skin surface; 2) as plaques placed on the skin surface, or at a distance not more than one centimeter from it; 3) as needles inserted into the diseased tissues.

In designing apparatus for any of the foregoing methods that use a high-intensity source, the primary problem is to provide working personnel with adequate shielding from radiation. They must place the patient in position and then position the source.

There are two practical solutions to this problem. One is the transit method whereby the source is kept in a far-removed shielding container during the positioning process. After the operator leaves the room and is behind a protective barrier, the source is brought into place over the patient by remote control.

The second design makes use of a shielding container that holds the source at all times. A shuttering device blocks the beam exit, or port. Or, the source may be moved within the container to bring it over the port for treatment to be returned later to the safe, or "parked," position.

Early Types

An early unit was that of Sluys-Kessler (page 45). It made use of 13 radium sources of 100 milligrams, each focused to a common center. Each source was shielded by two centimeters of lead. The maximum skin-to-source distance was six to eight centimeters.

A French hospital used an apparatus designed by Mallet (page 44). Each of the three radium sources were made of 10 milligram needles. Later the apparatus was redesigned to make use of 18 sources. Another French design was that of Regaud and Ferroux (page 44) that used a lead container six centimeters thick to reduce stray radiation.

Cheval and Mayer designed a unit used in Belgium in 1926. A large lead block provided shielding for the source. For movement to the OFF position the source was moved through a canal within the block.

In this country Stenstrom and Failla designed units early in the twenties. Stenstrom's unit (page 45) used multiple sources of radon totalling 1.6 curies (radon is the new radioactive body formed by the disintegration of radium). This apparatus was used at the State Institute for the Study of Malignant Disease in Buffalo, NY, now the Roswell Park Memorial Institute.

The Failla type of equipment, used at Memorial Hospital in New York City, was a lead container with two treatment ports. If not the first, it was one of the first in which serious thought was given to shielding as a major part of the design.

Lysholm designed one of the early radium units for use at the Radiumhemmet in Stockholm. The source was suspended on a rod so that it could be moved within a lead shielding cylinder to control radiation field size. Somewhat later Sievert also designed a unit for use at the Radiumhemmet making use of the transit principle. The radium source, when not in use, was stored in a large lead container. A tube connected the storage container to a remote treatment head, or "nozzle." Through means of a vacuum unit, the source was transported to the treatment head by air pressure and returned to the storage container by vacuum. A still later design by the same man made use of a shielded container with the treatment nozzle rigidly connected to it through a short right-angle tube. When not in use, the source was contained in the shielded container with the port blocked by a motor-driven shutter.

The transit type of radium unit (opposite page, left) probably reached its most advanced design in Great Britain as a result of the work of the late Dr. L. G. Grimmet. It combines a high degree of flexibility with good shielding protection for the operator. Pneumatic transfer is used between the storage container and the treatment nozzle. The tube is flexible and the nozzle is shielded with a tungsten alloy.

There are other more recent designs, notably those combining the transit and shutter types and one making use of mercury as the shielding medium.

Cobalt-60 Irradiator

The percentage depth dose of radiation increases with the skin-to-source distance. Accordingly, a source yielding a greater radiation intensity than that available from radium would make it possible to design a teletherapy unit utilizing the longer distances. Inherent to the design however would be the shielding problem imposed.

The Cobalt-60 irradiator shown on page 44 was constructed according to the design of Britain's Dr. L. G. Grimmet, who became Head of the Department of Physics of the M. D. Anderson Hospital in 1950, and who was associated with this institution until he died in 1951. These were the principal design requirements laid down by him. . . .

- Simplicity and safety in loading the Cobalt-60 into the unit.
- Simplicity in turning the gamma-ray beam on and off.
- Flexibility of vertical adjustment and orientation of the beam in any desired direction.
- Provision for the usual clinical accessories such as: visual field definer, diaphragms, beam pointers, and so on.
- Adequate protection for operators.

Essentially, the unit consists of a cylindrical shielding head, source wheel, collimator cone, and treatment cone (cutaway, left).

Shielding Head—The design called for a shielding container in which the source was to remain at all times. Because uranium wasn't available, a choice had to be made between lead and tungsten alloy. Lead—although readily available and considerably cheaper than tungsten—would call for a larger and heavier container. And in addition, it might have to be reinforced against the possibility of cold flow over a period of several years.

A tungsten alloy was therefore decided upon for the shielding job. Five disks each 13 inches in diameter are used; the usual machine tolerances produce surfaces along which interplaner leakage is negligible.

Source Wheel—A rotating disk with the Cobalt-60 source mounted in a recess is used to bring the source into the ON position and to act as a shutter for the OFF position. Sides of the disk are stepped to form a radiation barrier. The 1250-curie source (1000-curie effective) consists of four wafers measuring $2 \times 2 \times 0.25$ centimeters, stacked in a steel box to permit magnetic handling.

Operating through an electromagnetic clutch, a small unidirectional motor rotates the disk, or source wheel, to the ON position (in line with the beam exit). It's essential that the source remain in this position throughout the treatment. This is accomplished by driving the disk until it strikes a mechanical stop. The motor continues to run during treatment, holding it in position through slippage of the clutch. Connected to the driving mechanism is a spring that's placed under tension as the disk is driven to the ON position. Terminating the treatment is a timer that opens the energizing circuit to the clutch, thereby permitting the spring to return the source to the OFF position. In the event of power failure the mechanism also returns the source to the OFF position. Should the operator enter before the treatment is terminated, an interlock switch on the treatment-room door opens the driving circuit. Furthermore, if all other elements fail, a handwheel attached to the disk permits the source to be returned to the safe position.

Cones—Attached to the lower end of the shielding cylinder is a lead collimator cone 31 centimeters long (producing a beam of parallel rays). Treatment cones that fit over the end of the collimator increase to 50 centimeters the over-all skin-to-source distance. Any field size up to 15×15 centimeters can be accommodated by the treatment cones. To reduce secondary electron emission both cones are lined with a material having an intermediate atomic number.

The collimator can be turned through 360 degrees to permit rotation of square and rectangular fields. A high-intensity aircraft lamp and a mirror are mounted inside the collimator. They provide an illuminated area on the patient's skin coinciding with the radiation field.

To keep one side free of encumbrances the unit is mounted on a telescoping structure (page 44, top). This feature enables the operator to position the unit without interference. It can be rotated 330 degrees on its horizontal axis. The three-element telescoping structure permits vertical travel of 36 inches. A counterweight ratio of 2:1 facilitates adjustment with minimum effort.

All control equipment is contained within a small cabinet designed for desk mounting.

Looking Ahead

Availability and cost of the source will generally determine the future of Cobalt-60 teletherapy. Cobalt-60 can be produced efficiently in nuclear reactors with thermal neutrons but at present Canada's Chalk River pile is the only producer of high-activity sources.

The chief saving comes from the need for a smaller space in which to house the Cobalt-60 source. Until it becomes available at much lower cost, or another artificial source is accessible, the supervoltage x-ray machine will not be supplanted by artificial radioactive sources.Ω

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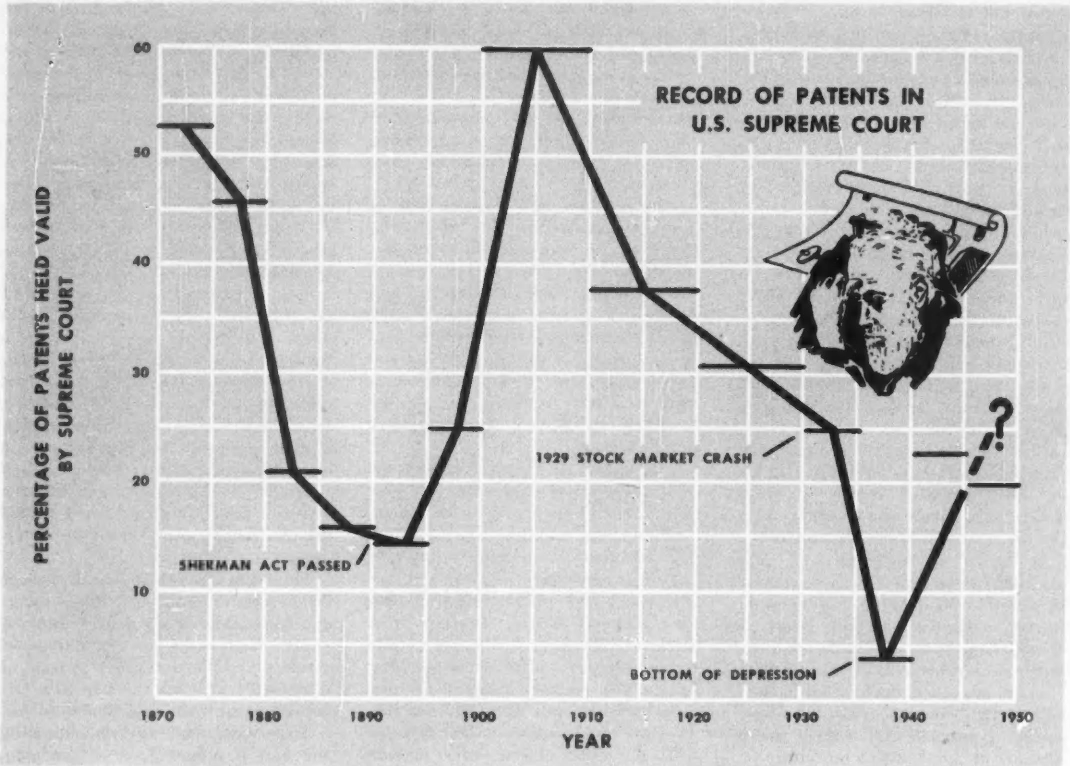
Author of numerous papers on radiation, x-ray equipment, and related subjects, Mr. Trout is Technical Advisor to the Manager of Marketing. Mr. Vlach, supervisory Project Engineer, is responsible for the design of x-ray equipment. He handled the mechanical design of the Cobalt-60 teletherapy unit. Both are in General Electric's X-Ray Department at Milwaukee.



WHETHER THIS CURVE POINTS UP OR DOWN IS OF IMPORTANCE TO INDUSTRIAL MANAGERS. IT SHOWS THE RELATIONSHIP BETWEEN . . .

Patents and Public Opinion

By H. R. MAYERS

Do the fitful wanderings of public opinion have anything to do with the functioning of the American patent system? If public opinion somehow does affect the standing of patents in our economy, how can such information be of value to industrial managers, engineers, and scientists?

Many people assume that courts have some absolute standard of validity by which patents can be judged. There is considerable evidence to suggest that perhaps the fate of a given patent presented in court depends not only on the quality of invention that the patent covers, but also on the particular court's attitude toward patent owners generally at the time in question.

As a starting point, let's look at the curve above which shows the action of the United States Supreme Court with respect to patents over the better part of the last century. (The horizontal lines through which the curve is traced show—for periods of five years in most cases, and for periods of 10 years in a few cases—the percentage of patents examined as to validity which the Court actually decided to be valid.)

The curve discloses some rather interesting things—

In the decade just prior to 1880, patents were obviously held in high regard by the Supreme Court. From this zenith of respect they fell, however, to a relatively low level between 1885 and 1895. About 1900 the cycle reversed itself again, and a new peak of judicial enthusiasm for patent interests was reached in the early part of this century. This was fairly well sustained until 1930 when once more the bottom fell out. The data seems to imply a second restoration of more favorable sentiment, beginning about 1940.

If there is any mystery about the convolutions of the curve, I should like to suggest that it can be resolved quite satisfactorily by reference to Mr. Dooley's famous statement to the effect that the Supreme Court follows the election returns. More particularly, it is believed that the status of patents before the Court depends quite directly upon how favorably business is regarded by the public.

To prove this point, let's consider—in historical perspective—the circumstances surrounding each of the major turning points on the curve.

In a period shortly before the beginning of the curve the economic doctrine of laissez-faire (noninterference with business) had attained general acceptance. This was signified in England, for example, by the repeal in 1844 of the principal statutes imposing restraints on the nonfraudulent practices of businessmen.

In this country the people of the 1860's and 70's had seen the completion of the first important phase of the building of the railroads and had become accustomed to the violent play of economic forces which accompanied that event. There was little or no tendency, at least on any organized basis, to criticize the activities of business or the tools used by business to speed the development of the country's frontiers. In this setting it was natural that the businessman or inventor coming into court to enforce a patent should receive a favorable hearing. The part of the curve which pertains to the years 1870 to 1875 shows that this was in fact the attitude of the Supreme Court judges.

During the following decades other important interests however began to assert themselves. One evidence of this was related in the *Yale Law Journal* for 1926–27 as follows—

> During the eighties there spread over the southern and western section of the country another great farmers' organization, known as the National Farmers' Alliance, which by 1890 claimed a membership of between three and four million farmers. Several hundred thousand farmers were also organized in a Northwestern Farmers' Alliance. These organizations demanded, among other measures, government regulation of railroads and the restriction of patent rights.

In 1890, crystallization of this sentiment came about with the passage of the Sherman Antitrust Law. It was directed, presumably, at meeting the popular demand for the control of trusts and the prevention of restraints of trade.

It is interesting to note, and is entirely consistent with our main idea, that at almost precisely the same time the status of patents before the courts hit its first low point. This is borne out not only by the curve but also by the pronouncements of the courts themselves. For example, Judge Putnam of the First Circuit Court of Appeals in a concurring opinion in the Gamewell Fire Alarm Company vs the Municipal Signal Company case (1894) said—

> . . . If I felt at liberty to proceed in this case . . . on my understanding of the tendency and practical effect of the decisions of the Supreme Court during the last few years which have sustained so many decrees in the circuit courts holding patents invalid . . . and reversed so many in which the patents have not been held invalid . . . I could not concur in any opinion sustaining the validity of any of these patents.

"If there be any mystery . . . . I should like to suggest that it can be resolved quite satisfactorily by reference to Mr. Dooley's famous statement to the effect that the Supreme Court follows the election returns. More particularly, it is believed that the status of patents before the Court depends quite directly upon how favorably business is regarded by the public."

It is not so easy to document the reasons for the change toward an entirely different viewpoint that seems to have occurred almost from the day the Sherman Act was passed. But everyone knows that it occurred and that the following decades were, on the whole, periods of considerable freedom of action for business. It is as though the public, having attained the object of its desires in the passage of the Sherman Act, concluded that it might have gone too far and expressed itself in ways that tended to prevent too rigorous an application of the restrictive weapon of its own creation.

Regardless of the explanation, we know that the following period from 1900 to 1929 provided a climate that was favorable to business—a climate in which business was given considerable freedom for effective development.

The significance of this, in terms of patents and patent law, is interestingly reflected in a letter written in 1914 by the patent counsel of an important building materials manufacturing company to the president of that company. The following excerpts are especially pertinent—

> The U. S. Courts—particularly in New York and Chicago—have gradually changed from the views of patent law fixed in decisions handed down, for the previous 50 years, and are swinging heavily to the side of the patentee in all cases where the alleged invention has gone into extensive public use.
>
> The practical phase of the situation is that we must be more careful to avoid even remotely infringing patents.

Events beyond this point are of such recent history that they need very little documentation. For it is within the common memory that the stock-market crash of 1929 was the signal for a concerted ideological attack upon business from which it is only now recovering. One prong of this offense was aimed directly at the patent system and, without question, played its part in bringing patents to the level of low repute shown by the curve between 1935 and 1940.

Because of our interest in trying to determine our present status and our direction—especially in regard to the public and judicial evaluation of patents—it seems worthwhile to attempt a fairly careful examination of the currents of sentiment in both areas over the past few years.

If we take the curve at its face value, it seems to show a significant upturn on the judicial front from the low point reached just prior to 1940. But does this trend conform to the trend in public opinion?

One way to find out is to consider the year-to-year changes in the statements of public officials in positions which require them to have some interest in remaining in tune with public sentiment. To begin, let's examine a quotation from the message of President Roosevelt to Congress on January 3, 1938, a year that coincides very closely with the low point of our curve—

> There are practices which most people believe should be ended. They include (among other things) the use of patent laws to enable larger corporations to maintain high prices and withhold from the public the advantages of the progress of science.

"The Constitution never sanctioned the patenting of gadgets . . ."

PATENTS AND PUBLIC OPINION (Concluded)

As a spokesman for the same viewpoint, Thurman W. Arnold, Assistant Attorney General, U. S. Department of Justice, testifying before the Temporary National Economic Committee on December 5, 1938, said—

> The law at present affords to the patent owners such a wide choice in exploiting a new industrial art that it offers wide opportunities for the restraint of trade.

Is it any wonder that in an atmosphere so charged with hostility the Supreme Court, if to any degree attuned to the political pitch-pipe, should react harshly toward patent owners? The curve shows that it did so.

But has the climate improved? Does the final upturn of our curve forecast better things ahead?

No more reliable barometer on this question is known than the public statements of the Department of Justice. On this whole issue it has (perhaps quite properly) seemed to regard itself as the keeper and recorder of the King's conscience. Thus, in hearings before the House Subcommittee on the study of monopoly (July and August 1949) we find that Attorney General Tom C. Clark said—

> We do not want to do anything, of course, that would discourage people who are engaged in trying to patent various techniques.
>
> I remember some 30 or 40 years ago a fellow said they had no more use for him over at the Patent Office because all of the inventions had already been perfected. He was wrong. And we do not want to do anything to discourage inventions or to contravene the statutes in the issuance of patents and inventions.
>
> I think that you would find that there are quite a number of abuses. I think we are getting them straightened out now very well.

And in October, 1948, John C. Stedman, Trial Attorney and Patent Specialist in the Antitrust Division of the Department of Justice, said in a paper presented before the New Jersey Patent Law Association—

> For my part let me assure you that the Antitrust Division is antitrust, not antipatent. We are fully aware of the important contributions the patent system has made to this country's development. Properly administered, patents have a legitimate, important, and useful place in our economy which we fully recognize and respect.

I believe that the above remarks properly foreshadow, underwrite, and to a large extent explain the more fortunate outcome of patent litigation in the last few years.

That the Supreme Court's present viewpoint does not establish an impossible standard of invention is shown by the fact that in 1949 (in the Graves

vs Linde case) the entire Court united in holding valid the process claims of a patent for an important welding invention. And in the same year a majority of the Court upheld as valid a patent on a pinball machine!

Even the two Supreme Court decisions on patent validity handed down since 1950, which are less heartening statistically because they are adverse to the patents that they involved, should be encouraging to persons of technical competence, because of the entirely tolerable tests of patentable invention that they declare. Indeed, one could hardly conclude this phase of the discussion with a statement more satisfactory than the following, taken from the concurring decision of Justice Douglas in the so-called A&P case, a decision reported by some newspapers as hostile to the patent system—

> The Constitution never sanctioned the patenting of gadgets. Patents serve a higher end—the advancement of science. An invention need not be as startling as an atomic bomb to be patentable, but it has to be of such quality and distinction that masters of the scientific field in which it falls will recognize it as an advance.

Surely neither industry nor the engineering profession should shrink from attempting to meet such a standard.

In July of this year Congress passed and the President signed a new law collecting in one place and fully revising previous statutes pertaining to patents. It is extremely encouraging to those interested in a vigorous patent system that this comprehensive new law has apparently changed the existing law only in ways which are favorable to inventors.

From all this, then, we can draw a general conclusion—

Broadly, it is felt that the analysis justifies our basic idea that the strength and value of patents in the courts, and hence in the marketplace, will be found to follow very closely the level of regard in which business and industry are held by the public. This is of importance to the industrial managers who are responsible for the authorization and control of development and research activities of their various companies. Also, the engineers and research personnel who are responsible for producing inventions have a similar interest in the question of whether they may expect to become the receivers of patents that will be sustained by the Courts.

At present it is believed that business has made measurable progress in recapturing some of the esteem which it unquestionably lost in the depression era. This consideration, if true, justifies the assertion that one may take at face value the final upswing of the curve and conclude that the value of patents is again in the ascendancy.

Whether this movement will carry onward to peaks approximating those of 1870 and 1905 depends upon considerations that are imponderable at present. In the final analysis it depends upon the success of business itself in regaining the full confidence of the American people. Ω

Mr. Mayers is an engineering graduate of the University of Maine and a graduate of the George Washington University Law School. He has been with the General Electric Company at Schenectady since 1930. He is now Manager, Patent Services Department, Legal and Patent Services Division.

Aid for the High-temperature Designer

By JAMES MILLER

● **New parameter predicts how stressed materials behave at high temperatures over periods of time. Information that required a year to get is obtained in a week or less**

● **Complete rupture characteristics of a metal can now be graphically represented in a single curve. Extrapolation of curves is done away with and guesswork eliminated**

Until now lengthy tests hampered the development of high-temperature metals. A short-time method was needed for determining how rupture and creep properties varied with time, temperature, and stress.

The stress required to rupture a material depends on the time it's applied and the temperature of the material being stressed. In conventional methods the temperature therefore was held constant and tests made of stress versus time—the stress being the amount necessary to rupture a material or to cause a given amount of creep. (Creep is the permanent deformation that usually precedes rupture in stressing materials to the breaking point.) This method gave rise to a *series* of constant-temperature curves needed to determine the rupture and creep properties of a single material.

Each curve was then extrapolated to find the desired values of time and stress. For it was rarely practical, economically or otherwise, to run tests over the service life of the part. There was more to extrapolating the curve however than just extending it after you'd plotted several points.

Curves of stress against time don't follow a given relationship. In fact, they often show sudden changes in slope. And so it was necessary, for satisfactory extrapolations, to make tests lasting anywhere from several weeks to several years—depending on what you wanted.

Parameter Developed

But now with a formula we've developed you can get a year's information in a week or less. And it's more accurate, too.

Key to the solution is a parameter that predicts long-time data with good accuracy from comparatively short-time tests, resulting in a single *master* curve for a given material. It was the logical outcome of theoretical work on the deformation of metals by many investigators.

For a long while we have known that many rate processes, such as chemical reactions, viscous flow, diffusion—and *creep*—are affected by temperature according to the equation

$$(1)\quad E = A\epsilon^{-Q/RT}$$

where

E = rate
A = constant
Q = activation energy
R = gas constant
T = absolute temperature, degrees Rankine

The activation energy Q for creep is constant for a given stress. And since the time until a certain amount of creep or rupture occurs is *inversely* proportional to the creep *rate*, you can substitute the new variable $1/t$ for E in equation (1). This done, take the natural logarithm of both sides of the equation and convert to common logarithms. This gives

$$(2)\quad T\,(C + \log t) = Q/2.3R = \text{Constant}$$

for a constant stress.

According to equation (2), stress is a function of the parameter $T\,(C + \log t)$. And if time t to rupture at a given stress and temperature is known, you can calculate t for the same stress at any other temperature. It's simply a matter of determining the constant C.

The values of C are the most interesting and important things about time-temperature relationships. They're close to 20 for most metals when t is expressed in hours. (The parameter $T\,(C + \log t)$ was first used to describe relationships between time and temperature in connection with the tempering of steel.) If you rewrite equation (2) as

$$(3)\quad C + \log t = Q/2.3RT$$

and remember that $Q/2.3R$ is constant for a given stress, you can see that when T becomes large and $1/T$ goes to zero, C is equal to a minus $\log t$. A plot of $\log t$ as a function of $1/T$ should then produce a set of straight lines—one for each stress—intersecting the $\log t$ axis at a value of minus C. Plots of such curves are shown in Figs. 1 and 2.

The table on page 53 lists values of C for a number of materials. Notice that all but two are between 17 and 20, a spread that could result from experimental error. Two materials have values that differ from 20 by more than the possible experimental error. And so, in using the parameter, it appears that some value other than 20 is required in unusual cases. (Another researcher calculated C based on the thermal vibration period of atoms. He got a value of 18.4. In connection with the tempering of steel C was found to be 20.)

From the development of the parameter let's turn to its use.

Master Rupture Curves

To show you how experimental data conforms to calculated data, two typical alloys were chosen for which complete sets of rupture data were available.

Rupture stresses for the two materials plotted as a function of the parameter $T(20 + \log t)$ are shown in Figs. 3 and 4. All values of the parameter for a given material and stress fall at the same point,

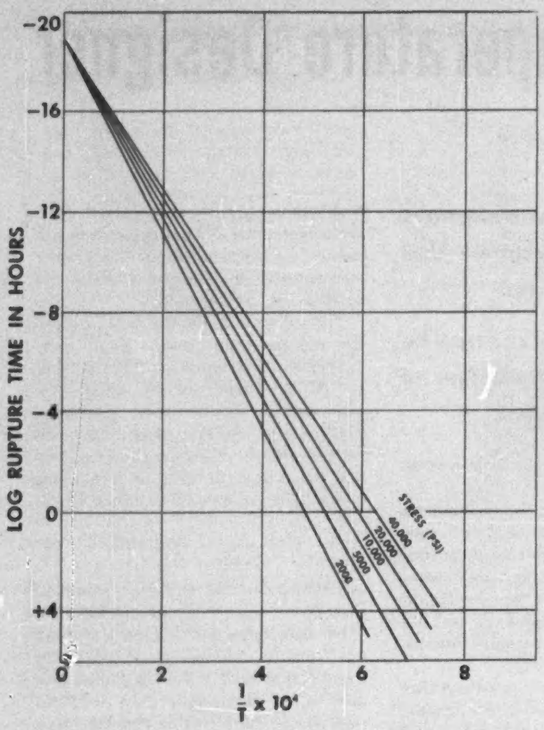


FIG. 1. TIME AXIS INTERCEPT IS C FOR CARBON-MOLY STEEL

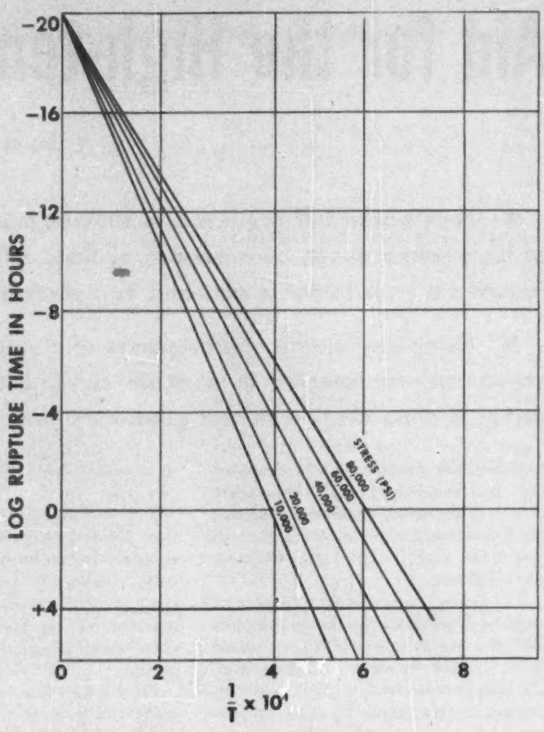


FIG. 2. VALUE OF C FOR THE S-590 ALLOY IS EXACTLY 20

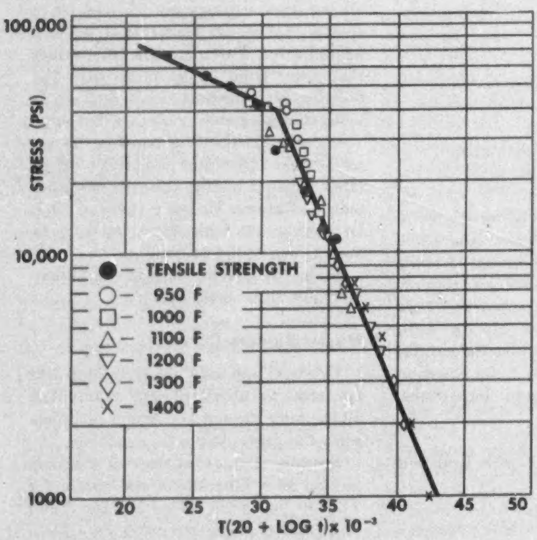


FIG. 3. MASTER RUPTURE CURVE FOR CARBON-MOLY STEEL

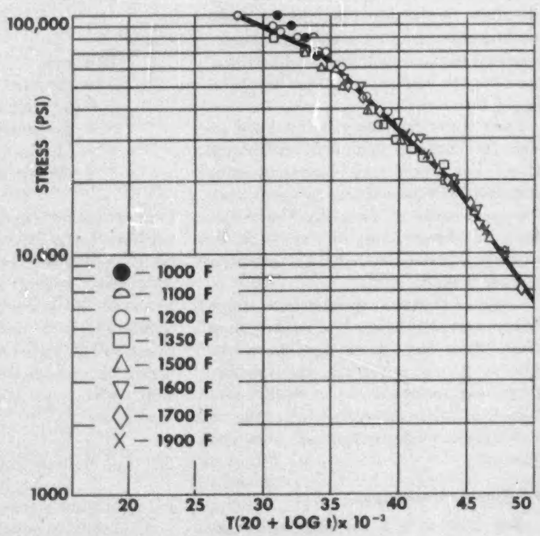


FIG. 4. MASTER RUPTURE CURVE FOR THE S-590 ALLOY

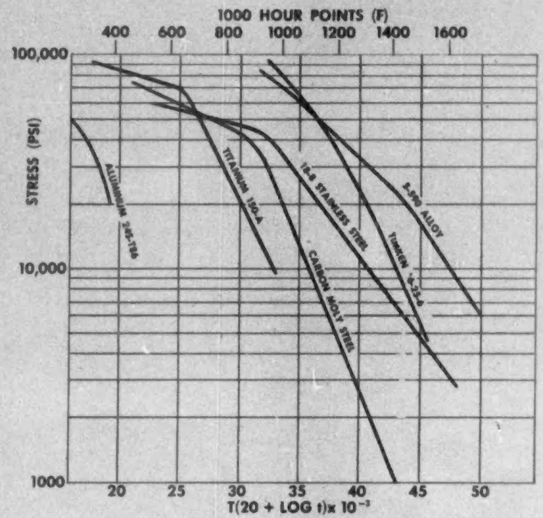


FIG. 5. MASTER RUPTURE CURVES FOR SEVERAL ALLOYS

VALUE OF C IN PARAMETER $T(C+\log t)$ FOR SEVERAL ALLOYS

Aluminum 24S-T86	17
Titanium D9	20
Low-carbon Steel	18
Carbon-moly Steel 12 Cr – 3 Mo – 0.2V Steel	19
18–8 Stainless Steel	27
25–20 Stainless Steel	15
Timken 16–25–6	20
S-590 Alloy	20
S-816 Alloy	18

t in hours, T in degrees R
Degrees R = degrees F + 460

giving rise to a single curve covering the whole range of time and temperature. That this is true is evidenced by the experimental data whose plots are in close agreement with the curve. Plots of experimental data represent temperatures that range over several hundred degrees and times that range from a tenth of an hour to several thousand hours.

The high-temperature tensile strengths shown in the figures were plotted on the assumption that a tensile test is equivalent to a tenth-of-an-hour rupture test. This isn't strictly true but shows fair agreement with the curves. (An explanation of this is that a rupture test consists of a constant load applied for the duration of the test. In a tensile test, although you start with zero load, it increases rapidly at first and is near the maximum for the greater part of the test which lasts about a tenth of an hour. The tensile strength is thus roughly equal to the tenth-of-an-hour rupture stress.)

A comparison of different alloys by the time-temperature parameter method is made in Fig. 5. Curves higher and further to the right indicate the stronger alloys.

A slide rule is available that does away with tedious calculations for converting time and temperature to the parameter $T(20 + \log t)$. Suppose you want to know what stress could be tolerated at a certain temperature for a definite length of time. Then, you'd simply set the two variables on the slide rule and read from it the parameter value. With this value you'd next refer to a chart and get your value of stress.

The parameter is also useful for predicting specific long-time data. Since $T(20 + \log t)$ is constant for a constant stress, you can write

$$(4) \quad T_1(20 + \log t_1) = T_2(20 + \log t_2)$$

for a constant stress. Short-time combinations of time and temperature can now be calculated that should have the same rupture strength as long-time combinations.

For example, 12 hours and 1350 F (1810 R) give the same value when substituted in the parameter as 1000 hours and 1200 F (1660 R). The rupture or creep strength for both conditions should therefore be equivalent.

Limitations

The accuracy of the foregoing method is usually ±10 percent of the stress, as indicated by the scatter of test data on the master rupture curves. In certain instances it may be larger. However, the accuracy of test data under ordinary conditions isn't much better than this. Errors involved in extrapolating conventional stress rupture curves are often much larger.

While it's theoretically possible for you to get long-time data from tests of only a few seconds by this method, there are several reasons why we don't recommend such short tests—except to get approximate data. For one thing, loading and other testing variables become more critical. What's more, to get an equivalent value of $T(20 + \log t)$ for a small value of time, the temperature may become high enough to introduce phase changes and grain growth in the metal, or other factors may change the time-temperature relationship of creep. Tempering and overaging obey the same relationship, however and are accounted for.

Despite its limitations, the time-temperature parameter steps up the development of high-temperature metals. It allows the design engineer to cut costs by conserving on the safety factor and greatly increases the capacity of metals testing equipment. These and other benefits are available. And as pointed out earlier, the complete rupture characteristics of an alloy can be represented by a single curve for comparison with other alloys. Ω

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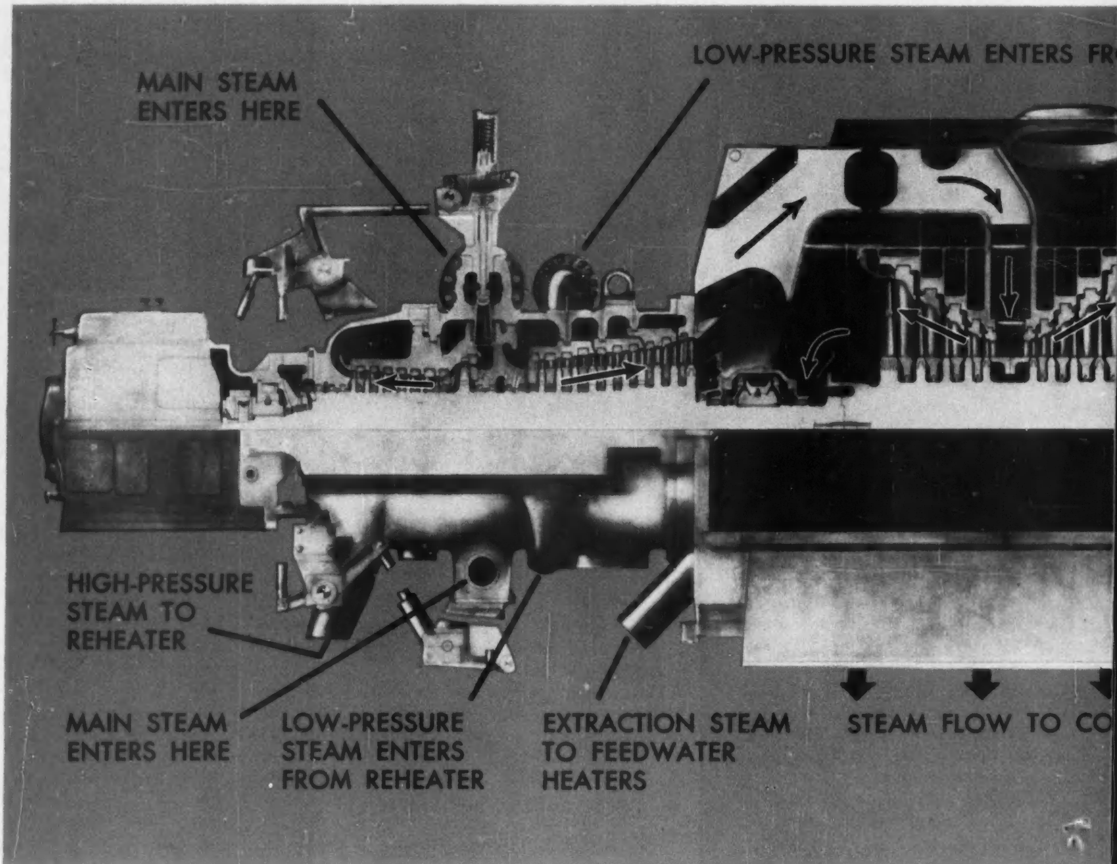
At General Electric Mr. Miller is a metallurgical engineer in the Metallurgy Section of the Thomson Laboratory, River Works, West Lynn, Mass. He is working on creep and rupture properties of alloys for steam and aircraft gas turbines. This year he received the Coffin Award for his work on time-temperature relationships.



FIRST MODERN REHEAT UNIT BUILT IN THE POSTWAR PERIOD IS A TANDEM-COMPOUND UNIT WITH A DOUBLE-FLOW LOW-PRESSURE ELEMEN

Reheat Turbines Are Shouldering the Increased

By ROBERT L. JACKSON

The first steam turbine was built and operated more than 2000 years ago. Its application to practical use however had to wait upon developments in manufacturing methods—methods necessary to produce a machine with the close clearances and high speeds of a steam turbine.

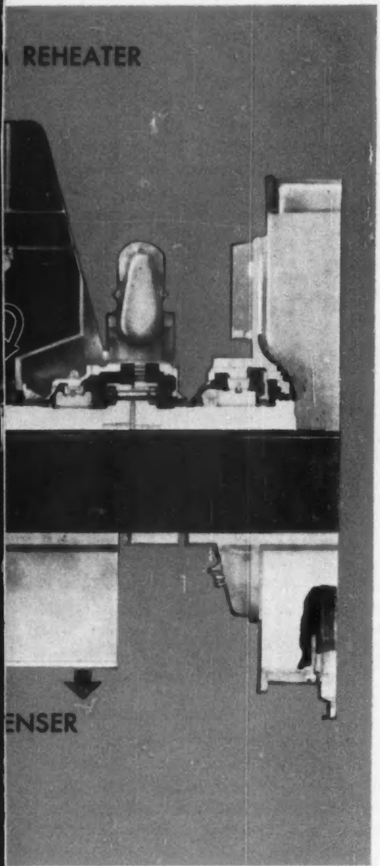
In 1883 deLaval, Swedish engineer, built the first practical steam turbine and shortly thereafter C. A. Parsons, British inventor, designed the first multiple-stage turbine. Since then progress in design has been rapid. And a continual reduction in the amount of fuel consumed per unit of output has taken place.

A product of such design progress is the modern reheat turbine. Its development is typical of general advances made over the years.

Reheat Cycle Introduced

A reheat cycle consists of: 1) expanding the steam part way between initial and exhaust pressures; 2) returning it to the boiler to increase the temperature; 3) completing its expansion in the turbine.

An increase of approximately five percent in thermal efficiency is made possible in this way. Reheating increases the temperature level throughout the expansion cycle and reduces the steam's moisture content in the low-pressure stages of the turbine. It makes for definite advantages in plant economy too. A reduction of the steam's moisture content decreases erosion with cor-



ND GENERATING CAPACITY OF 80,000 KW

Electrical Load

responding decrease in maintenance. In addition, the reheat cycle allows the use of smaller boilers, condensers, and feedwater heaters. Less cooling water is needed because for a given amount turbine capacity is increased 7½ to 11 percent.

In the twenties and early thirties improvement of existing turbine efficiencies was thwarted by available materials that limited steam temperatures to about 750 F. To offset this limitation the reheat cycle, or resuperheating cycle as it's less commonly called, was introduced.

Despite the success of the early units, development of new metal alloys in the middle thirties turned the trend back to the nonreheat cycle. The new materials allowed increases in steam temperatures to 900 and 950 F. Accordingly, thermal performance of nonreheat turbines could equal or better the reheat turbines, and without the installation and operating difficulties inherent to their early design. As a result we built only two reheat turbines from 1931 to the beginning of the postwar period.

After the second World War, fuel—like everything else—felt the pinch of inflation, and its higher cost made it necessary to build turbines of the greatest possible efficiency. Because new materials were not available to allow large increases in initial steam temperatures, the reheat cycle was again reverted to.

Our goal in the development of reheat turbines in the postwar period was twofold . . .

- Design a unit as simple and compact as a nonreheat unit.
- Keep the cost increase of such a unit at a level where fuel savings would economically justify its purchase.

The program has been a success. Approximately 63 percent of our total turbine kilowatts built or on order this year are reheat units. (In 1954 the figure will be approximately 80 percent.)

Double-flow Turbine

The first modern reheat turbine developed after World War II is the 80,000-kw tandem-compound double-flow 3600-rpm machine shown on the opposite page. It consists of two turbine rotors—high-pressure and low-pressure—bolted together in tandem. The low-pressure section is of two parts, each taking half the steam flow.

In this design, steam at 1450 psig and 1000 F is expanded across the high-pressure turbine, reheated at 450 psig to 1000 F at maximum flow, and then expanded across the low-pressure turbine. (The 450 psig pressure is proportional to the flow of steam passing through the turbine while the 1000 F reheat temperature remains constant.) Primary steam is admitted to the turbine shell at midsection and exhausts to the reheater at a point adjacent to the No. 1 bearing standard, or pedestal. From the reheater the steam enters the turbine shell at midsection once again.

With the initial and reheated steam entering at practically the same place, only the center portion of the turbine shell is subjected to high temperatures. This eliminates the severe temperature gradient that would exist were the machines designed with the flow all in one direction. It serves also to remove the highest temperature away from the bearings and water seals.

The foundation and space required for this type of unit are essentially the same as for a similar rated nonreheat unit. Having both primary and reheat admissions in the same casing results in the conservation of material and space, with better temperature distributions throughout all the metals.

Various improvements have since been made on tandem-compound double-flow turbines, and their maximum size has likewise increased. Some are now being built with ratings as high as 125,000 kw—enough electric power to supply the domestic needs of a city of 250,000 people.

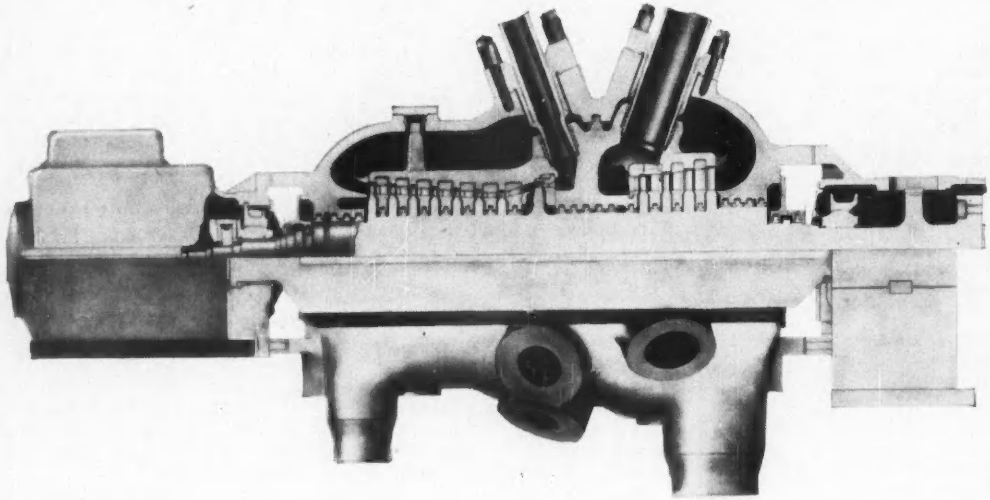
Triple-flow Units

Exhaust loss is the amount of velocity energy remaining in the steam after it leaves the last-stage buckets. It's always the goal to keep this loss at a minimum. Exhaust velocity is the ratio of steam flow to the area of the last stage: larger flows therefore require larger areas. Because larger exhaust areas in one stage are limited by mechanical stress considerations, a greater area is obtained by using more exhaust ends.

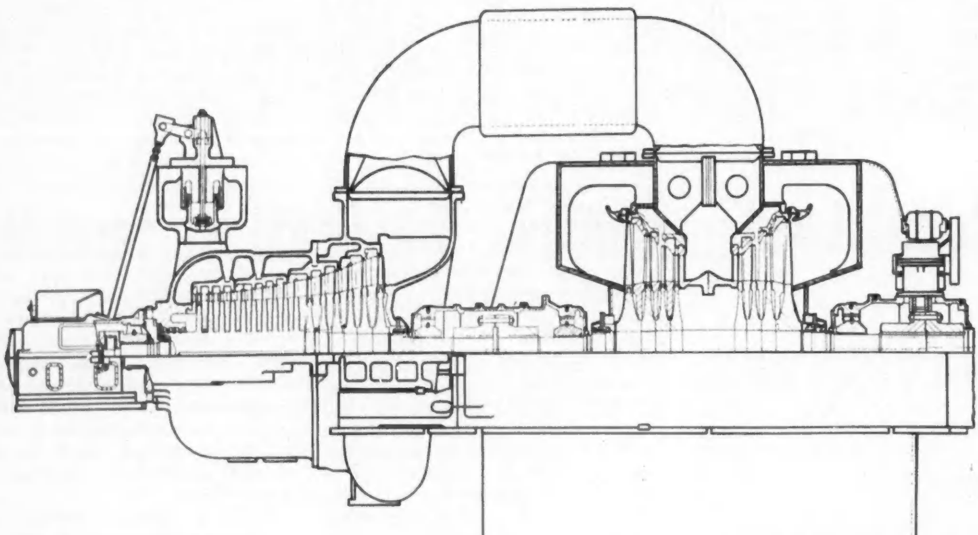
For units of 100,000- to 150,000-kw nominal rating the exhaust loss at normal back pressures would be excessive in a double-flow low-pressure section. Accordingly, a triple-flow low-pressure section with three exhaust ends is used. With such an arrangement it's necessary to separate the high-pressure section to keep the shaft spans at reasonable lengths—otherwise the critical speed at which maximum vibration occurs would approach the running speed.

The designs discussed so far are used for initial pressures up to 1800 psig, initial temperatures of 1050 F, and a reheat temperature of 1000 F. But two units now being built operate at pressure and temperatures that are the

Reheat Turbines (Concluded)



HIGH-PRESSURE UNIT of a 160,000-kw cross-compound reheat turbine runs at 3600 rpm and carries approximately 37 percent of the rated load. Steam to the low-pressure unit (*below*) is reheated in the high-pressure unit or as it crosses over



LOW-PRESSURE UNIT of cross-compound reheat turbine runs at 1800 rpm and carries remainder of 160,000-kw load. Advantages of this arrangement are a reduction in over-all length, the use of smaller size generators, and lower initial cost most advanced steam conditions for which a large turbine has ever been designed. These conditions are: initial steam at 2350 psig and 1100 F; reheating to 1050 F.

Incorporating an opposed-flow high-pressure casing (initial and reheated steam flow in opposite directions from adjacent points at the midsection), the machines are similar in principle to the double-flow design.

The inner shell includes all the high-pressure stages and consists of three parts: a center portion, exposed to initial steam temperatures, machined from a solid stainless-steel forging; and two adjoining portions, one extending toward the front bearing standard and the other toward the high-pressure exhaust, made of chromium-molybdenum-vanadium castings. The external valve chest (a pressure vessel where the main steam is admitted through a series of control valves to separate nozzle arcs in the first stage) and control valves are also of stainless steel.

The maximum size of tandem-compound units coupled to one generator has increased greatly in the postwar period. Several are on order for 200,000-kw maximum capacity.

Cross-compound Units

In the larger 3600-rpm tandem-compound turbines exhaust losses become quite high and it is advantageous to use cross-compound units. They consist of two separate turbines. The steam flows first through the high-pressure turbine and then crosses over to flow through the low-pressure turbine. Reheating is done as the steam goes from one to the other, or by reheating the primary steam as it expands through the high-pressure section. Cross-compound units are designed with both turbines running at 3600 rpm, or with the high-pressure unit at 3600 rpm and the low-pressure unit at 1800 rpm. When both are run at 3600 rpm, the advantages are a reduction in over-all length of the units, the use of smaller generators, and lower initial cost.

At the present time three different types of these units are being built. . . .

Unequal Load Split—This 160,000-kw unit has a 3600-rpm high-pressure turbine carrying approximately 37 percent of the rated load. The low-pressure section runs at 1800 rpm and carries the remainder. Both turbines comprising the unit are shown on the opposite page. The high-pressure turbine is of essentially the same construction as the high-pressure section of a 2350-psig triple-flow unit. The low-pressure turbine is a tandem-compound double-flow unit.

Equal Load Split—The 1800-rpm high-pressure turbine for this cross-compound unit is fundamentally the same as the 80,000-kw unit mentioned earlier, except that it has double the capacity. It's paired with a 3600-rpm quadruple-flow turbine. Both have identical generators and share the 160,000-kw load equally.

Adjustable Load Split—A third type of cross-compound unit was first designed for a rating of 150,000 kw, with initial steam conditions of 1800 psig, 1050 F, and reheat to 1000 F. It's possible to use this design for ratings as high as 265,000 kw. (This may be done by adjusting the load-split between the high- and low-pressure units to keep the volume of steam flowing in the cross-over pipes within reasonable limits.) It was developed in an effort to minimize the length of the low-pressure section and thereby reduce space requirements. In general, such an arrangement permits a reduction of approximately 10 feet in over-all turbine-generator length of the low-pressure unit.

The high-pressure turbine of this unit runs at 3600 rpm and generates 90,000 kw. It's of the opposed-flow type and similar to the 3600-rpm high-pressure turbines of the other cross-compound units.

The double-flow low-pressure turbine is rated at 60,000 kw. It runs at 1800 rpm and has two rows of 38-inch last-stage buckets.

Control

All the controls customarily used on a nonreheat turbine are required, plus some additional ones.

The steam in the reheat section of the boiler and its connecting piping contains considerable energy. With sudden loss of load, such as the opening of a circuit breaker, this energy will cause the turbine to overspeed. To prevent the speed from exceeding that required to trip the emergency governor, an intercept valve is used to shut off the unwanted steam.

Originally only one intercept valve was used, but the standard practice now is to use two. This modification permits either valve to be closed completely for testing any load, without causing more than a six to eight percent load drop. The valves are under control of a pre-emergency governor; they start to close at 101 percent of normal speed and fully close at 105 percent.

During starting, and also when operating at no-load speed following sudden loss of load, the temperature of the steam from the reheater will cause excessively high temperatures in the exhaust hood. The reason is that the steam from the reheater is at a high temperature: at no load or extremely light loads there isn't a sufficient pressure drop to convert the high temperature into velocity energy. Desuperheating sprays are therefore installed in reheat turbines. An automatic control turns them on when the control valves are in a position corresponding to five percent or less of the rated load, and when the intercept valves are open. Under all other conditions the sprays are off.

Expectations

A cumulative operating experience of 21 machine years has been gained on 12 tandem-compound double-flow, one tandem-compound triple-flow, and six cross-compound reheat turbines. It has served to show them as fully reliable and easy to operate as nonreheat turbines of similar types and ratings.

The total installed electrical capacity in the United States is presently about 75,000,000 kw, 72 percent of which is represented by steam turbines. Its growth to this figure follows a curve such that the capacity doubles every 10 years. Estimates of future growth point out that this rate will be continued or even increased.

By 1962 the total capacity will be approximately 150,000,000 kw. Put another way, in the next 10 years as much capacity will be installed as was in the preceding 50. Of this amount, more than 80 percent will be produced by steam turbines. According to present trends practically all of them will be reheat turbines of the larger sizes. Ω

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Mr. Jackson came to General Electric and entered the Test Course in 1940. He is at this time Section Engineer—Requisition Section of the Large Steam Turbine and Generator Department, Turbine Division, Schenectady. His responsibility is supervising co-ordination of turbine design with power station layouts.

What Does Industry Owe the Young Engineer?

By K. B. McEACHRON, JR.

At the present time the seniors in engineering colleges and universities are nearing the completion of a job most of them began four years ago—an education in engineering. They're beginning to think about the job they'll have in industry—what it will be like, and what demands it will make upon their abilities and knowledge.

Because most of them have received formal education in engineering, they will naturally try to select an engineering job, at least as their first one. But a typical engineering senior has had little opportunity to gain actual engineering experience, and his ideas of the job industry expects of him are liable to be hazy and uncertain. Even the reasons why he elected to study engineering some four or more years ago are probably not too clear.

Very few have ever considered that the engineer's task involves more than the technical side—the job of "making things." And it's only natural that this should be so because their time in high school and college has been occupied more with mathematics, physics, chemistry, and engineering subjects than with any others, such as liberal arts, or cultural, subjects. Consequently, such subjects as economics, psychology, or even English leave them pretty "cold."

Graduation from college, as has been said many times before, is truly a commencement—a time when the engineering graduate begins to learn from experience rather than from lectures or textbooks. This shift in emphasis is not always easy to make and explains why some men with excellent college records do not succeed in industry—primarily because they are unable to learn from experience. The purpose of the four years spent in college therefore has not been to teach students *what* to think, but *how* to think and how to learn from experience—the experience that they will receive in industry.

In a very real sense the engineering education is therefore just beginning. College has provided the young man with a start—a good start—but it can hardly be expected to provide him with all the education he will need to be successful in the next 40-odd years. Although college instructors have kept the students hard at work, the new job of learning from experience will prove to be an even harder task to many of these new members of industry.

What are the contributions that we industrialists can expect of the engineering graduate?

The job of industry is essentially the job of production—the production of goods that people want at prices they can afford to pay. Industry must therefore measure the value of its manpower against what that manpower can accomplish in improving production through lower cost or improved design. I can most easily sum up industry's attitude in recruiting technical graduates by saying that industry looks for men who have the ability to get things done. At first glance this may appear to be a very limited statement of qualifications but implied in it is the ability to get things done efficiently, to get the right things done, to get them done on time, and to get them done with the least interference with the responsibilities and jobs of others.

But how can the young engineer develop, early in his career, this ability to get things done?

First of all, he will need to develop a greater breadth of understanding and ability in technical matters. Most men graduating from college tend to be able to solve problems or think effectively in one specialized field, but they are not so well able to integrate their knowledge of several fields to solve an actual engineering problem. This naturally follows from the division of engineering education into such subjects as mathematics, chemistry, physics, electrical machinery, machine design, and others. One of the first tasks of the young engineer is to combine his knowledge of engineering fundamentals and the tools of engineering, such as mathematics, so that they can be used to solve effectively the actual problems of industry.

Let me illustrate what I mean by an example from the electrical equipment field. If you were to select some piece of equipment which, for its design, would require a knowledge of only electrical theory you might very possibly think of the transformer.

In the early days the principal objective in the design of transformers was improved efficiency. The early work in this field was therefore very much concerned with applying electrical theory to meet this objective. So successful have transformer designers been that such efficiencies today are very nearly 100 percent and the limit in efficiency is almost reached. Reduction in size, weight, and in cost, now assumes much more importance than it once did.

Improving insulation and methods of heat transfer—subjects that are more clearly chemical and mechanical in character—are consequently of great importance. Reducing the noise level of transformers is also a serious problem and one which is largely mechanical. An electrical engineer engaged in transformer design must therefore be able to combine his knowledge of electrical circuits with similar understanding of chemical and mechanical fields.

Second, the engineer in industry must not only be able to solve problems of a broader nature than those with which he has become familiar in college, but he also often faces an entirely different type of problem—one where he must use more imagination than mathematics. We know very little about how to develop ingenuity and what we do know about it doesn't seem to be applicable in most present college programs. Intimate contact with production—with the development of new products—

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Since his graduation from the Advanced Engineering Program in 1940, Mr. McEachron—author of many articles on education in industry—has been in directive charge of engineering training programs in General Electric. He recently was appointed Assistant to the Manager of Engineering, Household Refrigerator Department, Erie, Pa.

appears to be the best way to stimulate an interest in creating new devices and new ways of doing old things. The engineer thus must be prepared to "dream up" entirely new gadgets or machines, as well as analyze those already developed. It is for this reason that industrial representatives are so curious about the things students have made, the model airplanes they have built, or the "hot-rods" they have designed.

Third, the young engineer must develop the ability to work effectively with others in the industrial team—in the factory, in the sales office, in the laboratory. But first, industry expects him to do a good engineering job, and he cannot hope to substitute, for proficiency in technical fields, knowledge and understanding of such subjects as psychology, history, or economics. But as the young engineer accumulates practical experience, we can expect him to broaden his interests and thus extend the areas of his understanding beyond the purely technical problems. Some engineers, we have found, refuse to recognize this need and resent the fact that those who can develop leadership and the ability to work with people as they gain engineering experience are more in demand than those with somewhat more technical ability but who lack initiative and organizing talents. Here, as in the employment of people generally, the law of supply and demand operates. Refusing to recognize its existence does not change the fact of its effect. If a person doesn't wish to prepare himself for the type of work most needed, no one will force him to do so, but he must be prepared to accept a less responsible job.

How can industry help the young engineer obtain, rapidly and efficiently, these important abilities which most of them have had little time and opportunity to develop in college?

To high-school graduates preparing for the skilled trades, industry offers intensive apprentice training programs to provide these men with such additional skills as they need to make rapid progress. Many college men, on the other hand, feel that their education is complete upon graduation.

Education is very much like an expensive piece of production machinery. The more time and care we spend in designing and building it, the more necessary it is that it be used correctly and efficiently. The investment in such production machinery is so great that industry cannot afford to misuse it or waste time in putting it to work. Training programs help industry put a man's education to work. Thus the more extensive and expensive an education, the more valuable, both to industry and the individual, is a planned program of orientation and development for new men.

It is possible, of course, for a young engineer to develop on his own the characteristics previously described. Experience in industry with many thousands of men has shown that they develop these abilities more rapidly and more easily however where careful thought has been given to the use of engineering personnel and to the integration of the new engineering graduate into a company organization.

Just as all engineering schools are not alike, programs for engineering graduates in industry vary widely. Some of these differences will naturally be related to the size of the organization and its policies. But there are characteristics that I believe should be common to all the programs that you may set up in your company for the new engineer.

First, the training program should make it possible for the new engineer to gain during his early years the training and experience that it has not been possible for him to obtain in college, and to do so in such a way that at its completion he will be able to assume the full responsibilities of a professional engineer. Where the primary emphasis in college has been the study of fundamentals, the emphasis in industry must be upon the application of these fundamentals to actual engineering problems. The heart of an effective training program is therefore broad industrial experience. We have found that the new engineers gain such experience best through a series of short assignments in different sections and types of work. Where the company's business includes several lines of products, this will give him an opportunity to gain diversity of experience in this respect. Each training assignment should consist of actual work experience rather than observing how work is done. Not only will this emphasis on "learning by doing" make the new engineer a contributing member of the section to which he is assigned, but it is also the most effective way for him to gain practical experience.

The second characteristic of an effective program for technical personnel is the opportunity for the new engineer to continue his education in engineering. As suggested earlier, the course method of instruction used in most engineering colleges tends to produce "problem solvers" rather than "project solvers." Most young engineers sense a need for a type of classroom instruction that will integrate the course material given to them in college and direct the application of engineering fundamentals to current technical problems. In some cases, such instruction will extend the student's technical knowledge beyond that received in college.

The need for a classroom program of this type was recognized very early in General Electric by such men as the late Dr. R. E. Doherty (later president of Carnegie Institute of Technology) and the late Dr. A. R. Stevenson, Jr. In 1923, these men organized the Company's Advanced Engineering Program to help new graduates apply their engineering and mathematical tools to the solution of tough engineering problems. So successful was the operation of this program that in 1937 Dr. Stevenson organized a second program to discover and develop intuitive abilities in those young engineers who show unusual talents in this direction. While it is often difficult to select accurately and train effectively men with such unusual abilities, our experience with the Creative Engineering Program has been most rewarding. Most of these young men have never before had any real opportunity to demonstrate their ability in developing new devices or redesigning old ones. Even during the training period many of these young engineers develop new products. By the end of the training period, some even have patents to their credit.

The third characteristic with which industry should be concerned in setting up a training program is whether it offers within itself opportunity for leadership. It has been our experience for more than half a century that we can develop leadership in relatively young men by giving them the opportunity to supervise portions of the training program itself. Young men who have been with us only a few years are given almost complete responsibility for the organization of educational activities. (See "Development of Engineering Leadership" by E. H. Freiburghouse, Jr., May 1952 REVIEW.) Although such men naturally do not have the background that certain phases of the work require, they are encouraged to call upon others in the Company for assistance and guidance. No one, however, will make decisions for these young men. The enthusiasm which they therefore bring to such work is high. They have only a year or two in which to contribute their best ideas to the supervision and administration of the training assignments and classes. They are naturally eager to make the maximum improvement possible during the period of their responsibility.

The engineering student, while preparing himself for an engineering career, has learned to appreciate the importance of first determining his objective—what the problem is that must be solved. He then proceeds to collect all the data that might possibly help in the solution of the problem and he finally determines the method by which these data can solve the problem.

We can therefore expect that a young engineer upon leaving college will, in a similar fashion, attack his first and most important problem—how to gain such experience that he will become, as quickly as possible, a fully competent engineer. In seeking a solution to this problem, he will give careful attention to the ways in which it has been solved by many others before him—through participation in organized industrial training programs. As he studies this problem, he will recognize the great differences that exist in industrial programs and will naturally try to select the one which will help him to develop his abilities most rapidly and effectively.

It is thus industry's responsibility, as well as its opportunity, to provide such industrial training programs that the young graduate can make maximum progress in his engineering career. Ω

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What's Ahead in High-voltage Transmission?—

(*Concluded from page 43*)

(step-up and step-down) may equal line costs. Accordingly, it is highly desirable that the best transformer be chosen for a given application. It follows logically that, in addition to decreased insulation levels, the high circuit loadings allow for an increase in transformer unit size. The high reliability of transformers encourages the increased use of three-phase units, as well as increased kva ratings of the single-phase units.

The use of autotransformers of large capacity, both single- and three-phase units, are also finding important applications in the high-voltage systems now being developed. Increased use of forced cooling has resulted in substantial increases in kva without materially increasing the over-all weight and dimensions. All of these developments have resulted in an accelerated trend to large capacity units as summarized in the bottom curve on page 42.

Generators—Larger generating units are a result of the ability to transmit and transform power in large blocks. And larger generating units mean bigger step-up transformers, and reduction in the amount of high-voltage switchgear—all factors that are in the direction of further economy.

Voltage Control—It is also evident that by 1962 we will realize additional economies by an increased use of kilovar control of voltage by synchronous condensers and switched shunt capacitors. Bigger synchronous condensers and switched shunt-capacitor banks will result in large blocks of shunt capacitors being switched directly to the higher-voltage circuits. (Capacitors are already being switched at 115 kv.) Synchronous condensers and switched shunt capacitors can be expected to supplement each other to realize optimum system performance with best economy.

Series Capacitors—Manufacturers have already developed series capacitors with quick reinsertion and protective means so that they can be used to obtain additional economies for straightaway long-distance transmission of more than 200 miles. Based on the successful use of series capacitors in this country and in Sweden, the cost per mile for the transmission of electric energy can be expected to remain practically constant up to at least 600 miles.

Trends in system operation are broad. For instance, there will be more attention given to system efficiency, and the application of more efficient equipment based on loss evaluations, because losses become of increased importance when other costs are minimized. More attention will also be given to obtaining a low cost per kilowatt-hour as contrasted with a low cost per kilowatt. This will have its effect in the design of equipment.

The future may see even better balances obtained between investment and efficiency.

There will be an increased use of modern tools—such as the network analyzer and computing equipment—by the utility engineers for obtaining the basis for economic loading, dispatching, and contractual agreements for interchange of power between interconnected systems.

System designers will give emphasis to operating practice during system emergencies. This will reduce the capital investment required to attain a given degree of reliability. Full use of quick reclosing and automatic disconnection of load at preselected points can be employed. Such refinements in design and operating practices will be the natural outgrowth of a more complete understanding of system performance based on network-analyzer stability studies supplemented by field tests.

In the Next 10 Years . . .

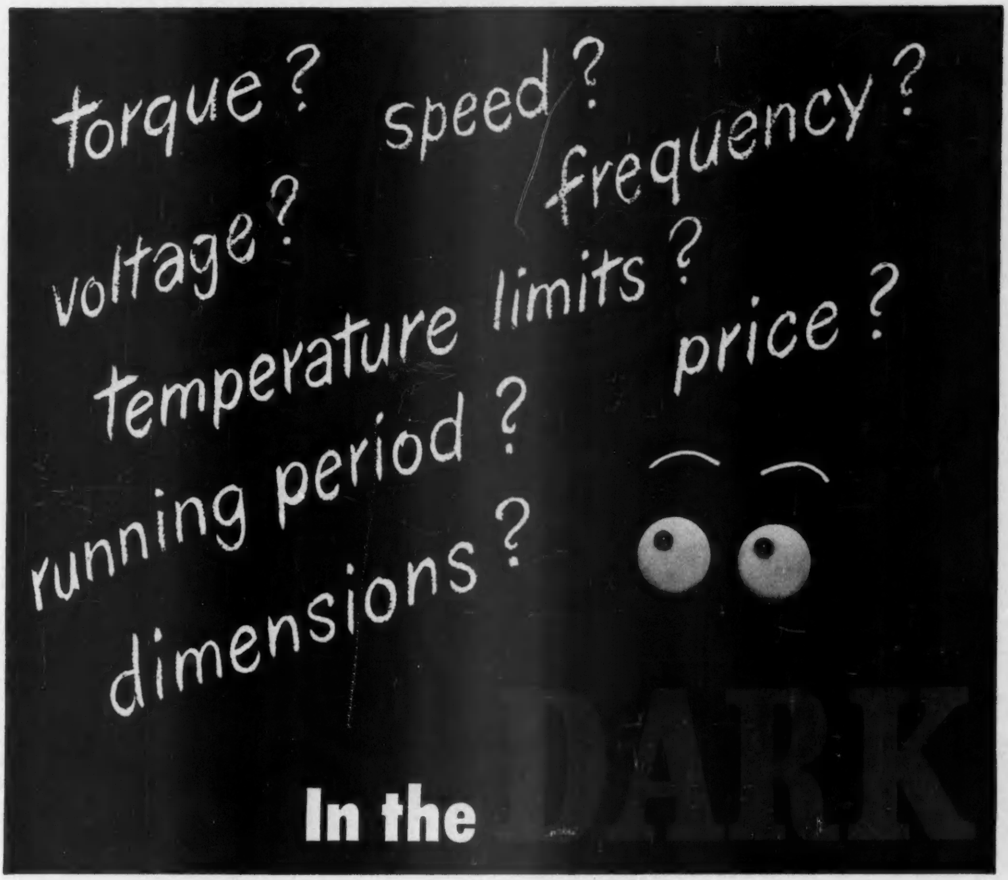
Power systems during the next decade will develop a pattern of design that will be characterized by a solidly interconnected high-voltage transmission system capable of high circuit loadings, high reliability, and maximum flexibility and capability in emergencies.

These systems will use large transformer banks, high-interrupting circuit breakers, reduced insulation, and reliable relaying and control.

Systems will be better co-ordinated, interconnected, and operated, and will be capable of transferring power in large blocks for considerable distances.

There will be more emphasis on standardization in system design.

Working together, the American utility and manufacturing engineers will be able to realize considerable savings in the next 10 years. Ω



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SAVINGS FOR YOU—As a designer or manufacturer these qualities offer you real advantages. Because you get higher output voltages, it is often possible to save in the design and specification of other components. Since they operate cooler, there is less heating of nearby circuit components, and slower rectifier aging.

LITERATURE AVAILABLE—Bulletin GEA-5524 gives testing directions. GET-2350 is a complete reference manual of application information on G-E selenium rectifiers. Write Section J461-25, General Electric Company, Schenectady 5, New York.

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Inductrols

(DRY-TYPE INDUCTION VOLTAGE REGULATORS)

Typical Uses:

- Motor speed control
- Rectifier control
- Heat control
- Dielectric testing
- Instrument calibration

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G-E Inductrols are small, dry-type induction voltage regulators, suitable for many applications.

Unit shown above operates from either 120 or 240 volt a-c circuits, with output variable—steplessly, with micrometer-fine precision, from 0 to 240 and 0 to 480 volts respectively. It will handle 5 or 10 amperes. Absence of brushes, contacts and commutator reduces maintenance. Unit has autotransformer efficiency.

You can get G-E Inductrols in hand-operated or in manually-controlled, motor-operated designs for circuits 600 volts and below. For complete information, see your nearest G-E sales representative, or write for Bulletin GEC-795, *General Electric Company, Schenectady 5, N. Y.*

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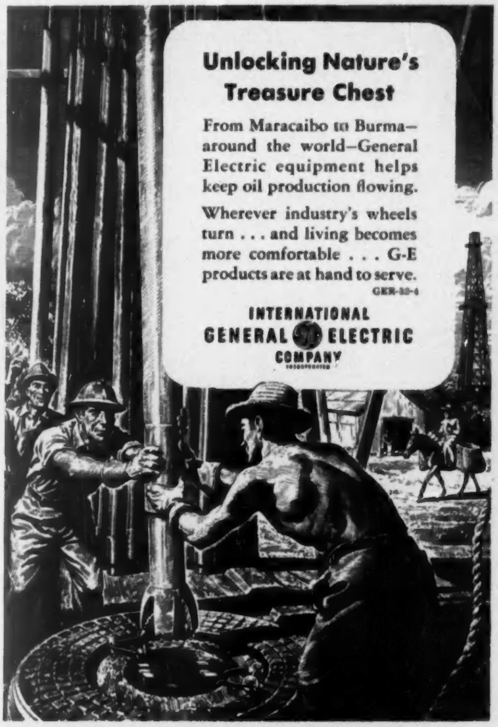
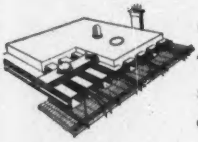


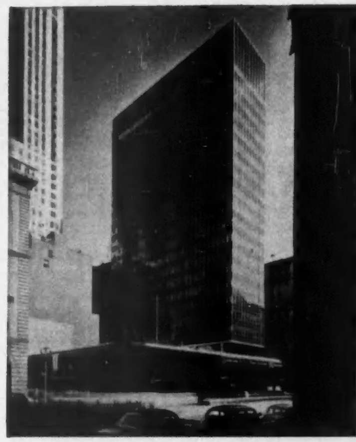
WIRING SYSTEMS *with Sales Appeal*

Here are three examples of modern G-E wiring systems for the Construction Industry. They add exceptional utility—and sales appeal—to the structures in which they are installed.



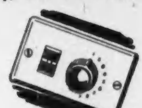
Q-Floor wiring system for office buildings.

This unique G-E wiring system uses the cells in Q-Floor steel floors for electrical raceways. No matter how changing tenants alter floor layouts, it will always be a simple matter to provide neat, unobtrusive electrical outlets for office machines, telephones, inter-office communication systems. One outlet is possible for each square foot of office space. The booklet "Your Stake in Q-Floor Wiring" gives full information.



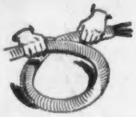
Lever House, New York City, uses G-E Q-Flooring.

Remote-control wiring system for homes.



Control of 9 circuits from one location is one of many interesting features of General Electric's low-voltage remote-control wiring system. Home buyers like the extra safety and convenience it offers. Builders like the way it helps sell homes. The booklet "Remote-Control Wiring System" gives full information.

Builder Romeo S. Picerne, Providence, R. I., installed G-E remote-control wiring in these homes.



Interlocked armor cable system for industry.

In the 440- to 15,000-v range, this remarkable cable permits factory management to wire or rewire their plants in less time, for less cost than with the usual raceway system. The system is permanent, for installation inside or out—yet with comparatively slight expense, it can be moved, expanded, or altered to fit every power need. Interlocked armor cable adds more value than it costs wherever it is installed. The booklet "Interlocked Armor Cable" gives full information.

For the booklets you want, write Section K4-1137, Construction Materials Division, General Electric Company, Bridgeport 2, Connecticut.

Midwestern tank plant rewired with varnished-cambric-insulated interlocked armor cable system.

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