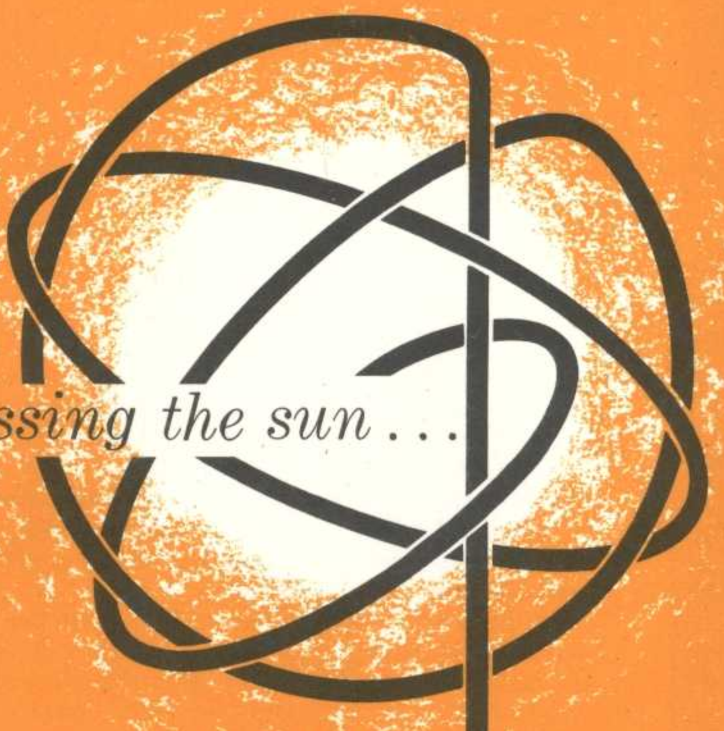
harnessing the sun . . .



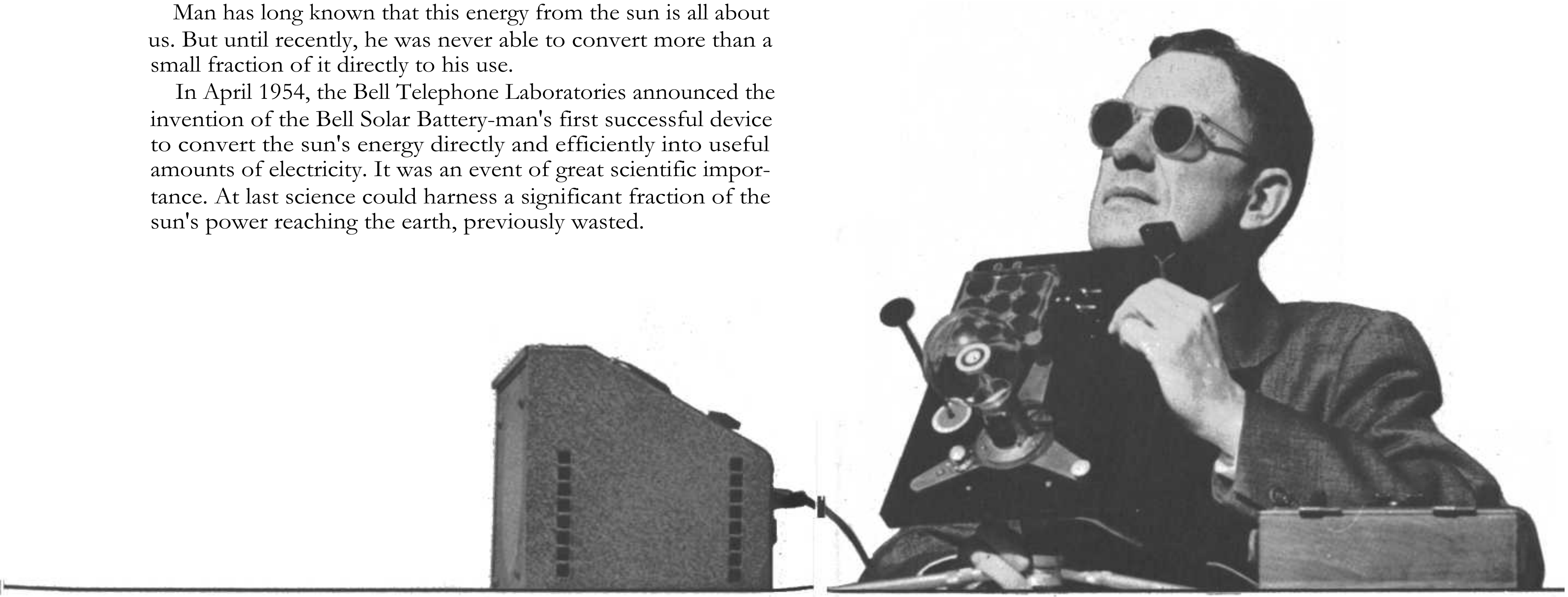
THE STORY of the BELL SOLAR BATTERY

ELECTRICAL ENERGY FROM THE SUN

For centuries, scientists have known that the sun releases vast amounts of energy. Most of it shoots off into space. But the earth alone receives an amount equal to more than a thousand trillion kilowatt hours each day. This is about as much as is stored in all the reserves of coal, oil and natural gas here on earth.

Man has long known that this energy from the sun is all about us. But until recently, he was never able to convert more than a small fraction of it directly to his use.

In April 1954, the Bell Telephone Laboratories announced the invention of the Bell Solar Battery-man's first successful device to convert the sun's energy directly and efficiently into useful amounts of electricity. It was an event of great scientific importance. At last science could harness a significant fraction of the sun's power reaching the earth, previously wasted.



FROM BASIC RESEARCH

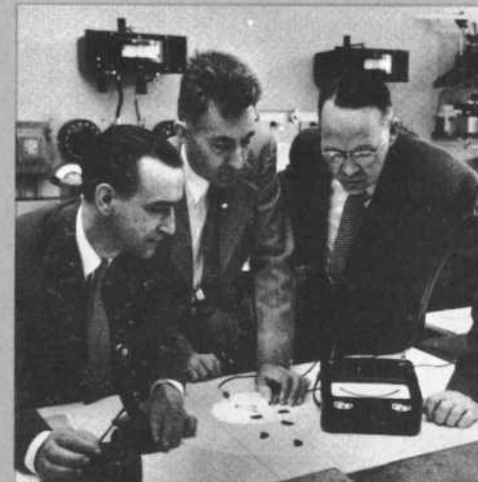
A three-man team of scientists - a chemist and two physicists - invented the Bell Solar Battery at Bell Telephone Laboratories. They made their discovery while doing basic research on the properties and characteristics of silicon, a semiconductor material. The specially prepared silicon used in the Bell Solar Battery study originally came from sand, one of earth's most abundant substances.

The Bell Solar Battery was made possible by a continuing basic research program on semiconductors. This program began immediately after World War II. It wasn't aimed at a specific invention or development but at acquiring more fundamental knowledge of nature's secrets. This same research project had already produced the transistor, invented by another team of Bell Laboratories scientists several years before.

While examining the properties of silicon in studies during the 1930's, scientists had noted that when exposed to bright light, silicon produced voltages under certain conditions. More exhaustive tests in the postwar research program confirmed the early findings and experiments with specially fabricated silicon structures led to better results.

By the time the Bell Solar Battery was announced to the public in April, 1954, its efficiency had reached six per cent. The best earlier photoelectric devices had never reached an efficiency above one per cent. Radiation-resistant cells such as those on Telstar now have an efficiency of twelve per cent in sunlight; nonradiation-resistant silicon cells have reached even higher efficiencies. Thus the Bell Solar Battery, using free "fuel," operates with an efficiency comparable to that of gasoline or steam engines.

Since it has no moving parts, the Bell Solar Battery should last indefinitely. However, on satellites exposed to the radiation of the Van Allen Belt, its efficiency and output will slowly decrease, although still remaining adequate for extended periods.



Inventors of the Bell Solar Battery, G. L. Pearson, D. M. Chapin. and C. S. Fuller check sample devices for amount of electricity derived front sunlight, here simulated by lamp.

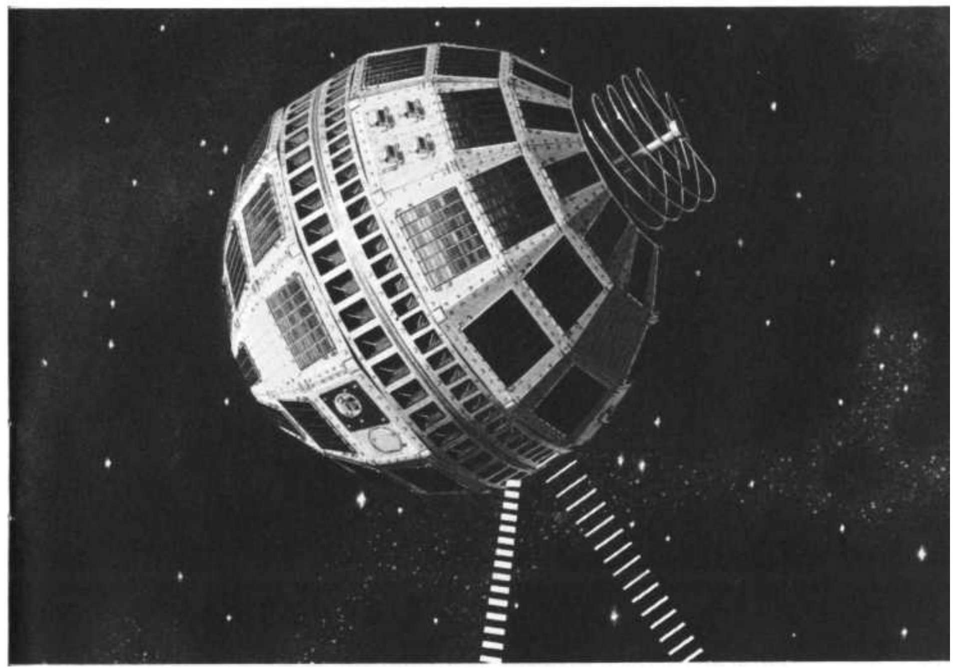
Sunlight striking the Bell Solar Battery held by D. M. Chapin, one of the inventors, provides the power to turn motor driven wheel.

SUN POWER AT WORK

The solar cell has already played a major role in the U. S. space program, and is now coming into use in several other applications. In these uses the solar cell provides over the period of use a cheaper source of power than does a chemical battery or other conventional power sources.

Without the efficient, dependable solar cells, continuous space communication would be almost impossible. For earth satellites the long life and small weight of solar cells have made them the standard for the U. S. satellite shots. Almost all of the many U. S. satellites have used solar cells to power their electronic equipment. Together with the Bell-originated transistor, it has made it possible for U. S. satellites to obtain much more scientific information per pound of satellite than Soviet satellites.

The technology and uses of solar cells are still advancing. New designs of solar cells, for long-life communication satellites, withstand exposure to high-level radiation while in orbit. For example, the solar cells in the TELSTAR satellites use p-type silicon, with an n-diffused layer which is much thinner than the p-layer in conventional solar cells used on the ground and in all previous satellite applications.



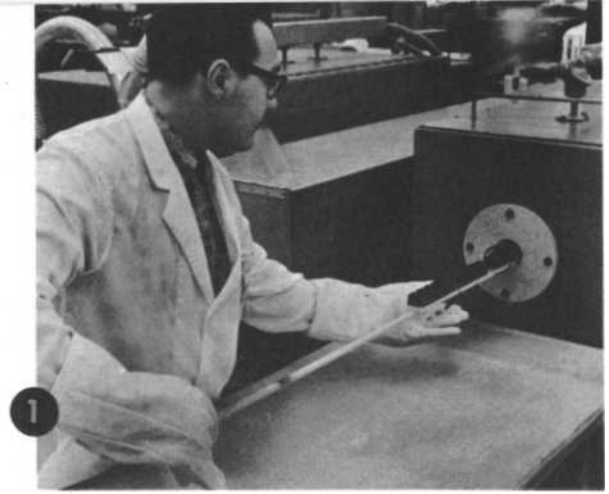
All the power (13.5 watts) to operate the TELSTAR satellites comes from 3600 newly designed n-on-p solar cells mounted on the satellite's skin.

THE PROCESS

Silicon, in crystal form, is the basic ingredient of the Bell Solar Battery. In making solar cells of the n-on-p type (as noted earlier, p-on-n cells are also manufactured for certain applications), a minute amount of boron is added to ultra-pure silicon at a ratio of about one part boron to a million parts of silicon. The two materials are melted together and formed into a single-crystal ingot of boron-doped silicon. This is called "p-type" silicon. The ingot is sliced into precise wafers by a diamond cutting wheel and then chemically etched.

Now the most critical phase of the entire operation begins. The wafer is placed in a quartz tube containing vapors of phosphorus compounds. The assembly is heated. During the heat treatment, phosphorus atoms are deposited on and within the silicon surface. These diffuse to form a thin layer. The layer's thickness is controlled by regulating the heat. When completed, the solar cell consists of the original boron-doped wafer of "p-type" silicon, and a phosphorus-doped layer, called "n-type" silicon.

These two types of silicon have different electrical conductivities. The boundary layer between the two regions is usually located less than 1/10,000 of an inch under the wafer's surface. It is called a "pn junction." It is this junction - the dividing line between the two different types of silicon - which is of such great importance in the successful operation of the Bell Solar Battery.



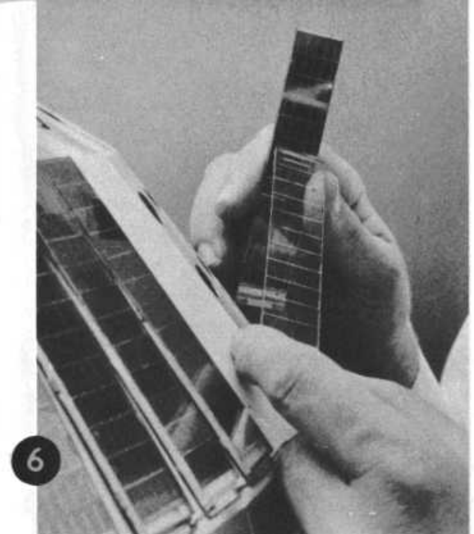
Production of a solar cell starts with growing silicon crystals of the p (positive) type which are then sliced into thin strips. These strips go into a diffusion furnace where an n (negative) type material - such as phosphorus - is diffused into the surface of the strips. Where the electrical conductivity changes from n to p is the pn junction, the essential feature of a solar cell.

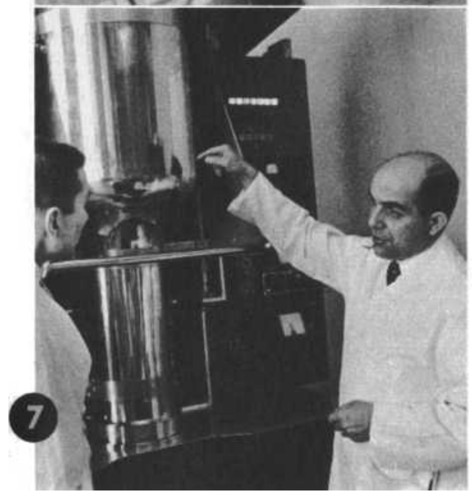
As the diffused n-layer is required on only one surface of the slice - the surface facing the sun - it is removed from the other side by air blasting.

To make electrical contact to the n and p-layers so that power can be drawn from the cell, the slices are mounted in masks. Next, electrically conducting layers are deposited from the vapor state through the masks onto the crystals.

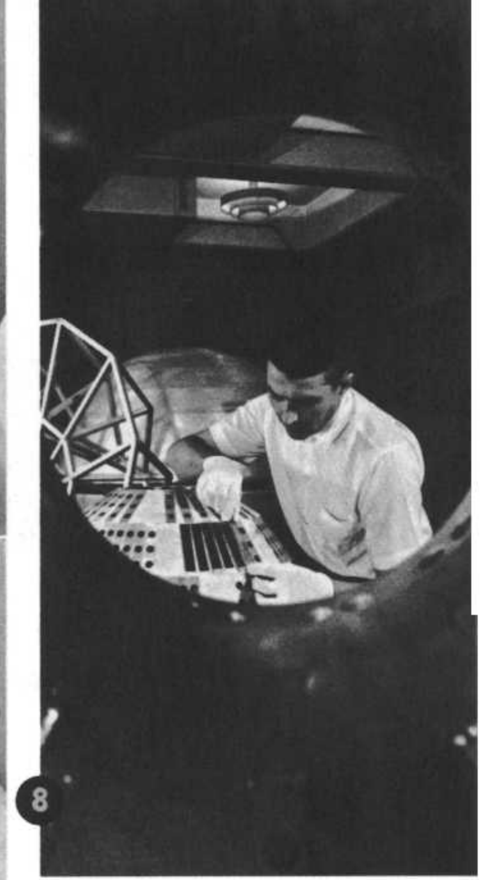
After manufacture, the solar cells are subjected to careful inspection and testing to assure that only the units meeting rigid specifications are used.

THE PROCESS



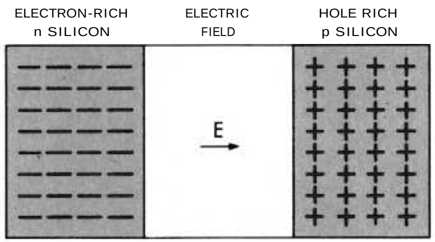


Also, for use on a communications satellite, a shield is needed to protect each cell from the harmful effects of space radiation. On the TELSTAR *satellites, a thin sheet of sapphire was used for this purpose and was fused to a metal support in a furnace.*



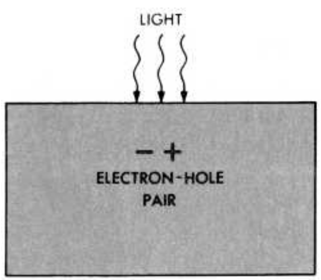
Finally, the cells are attached to the satellite. Internal conductors carry current to storage batteries, which in turn power the satellite's radio receiver and transmitter.

SILICON P-N JUNCTION



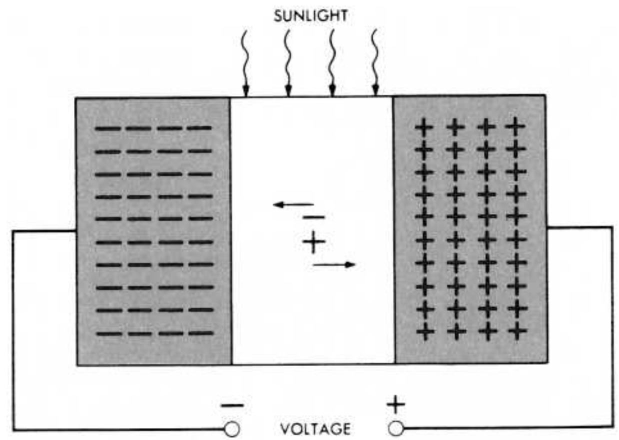
A semiconductor can have two kinds of movable electric charge, either negatively-charged "conduction electrons" (n-type) or positively-charged "holes" (p-type). If one region of a semiconductor is n-type while a neighboring region is p-type, there will be between them a strong electric field which tends to keep the positive holes in the p-side and the negative electrons in the n-side.

INTERNAL PHOTO-EMISSION



Light absorbed by a semiconductor breaks free some of the fixed or bound (nonconducting) electrons which hold the semiconductor together. When so energized, these electrons become "conduction electrons." They also leave behind in the binding structure "holes" which are positively-charged because the negative electrons are gone. This release of pairs of holes and electrons by the action of light is called "internal photo-emission."

HOW THE BELL SOLAR BATTERY WORKS



When internal photoemission takes place near a pn junction, the electric field forces conduction electrons energized by the light to go into the n-side, charging it negatively. Excess holes are similarly forced into the p-side, charging it positively. An electric circuit can use these charges in the same way that it uses the charge from a chemical battery. In this manner, silicon cells have converted as much as 12-15 per cent of the energy of incident sunlight directly into electricity.

OTHER USES FOR BELL SOLAR BATTERIES

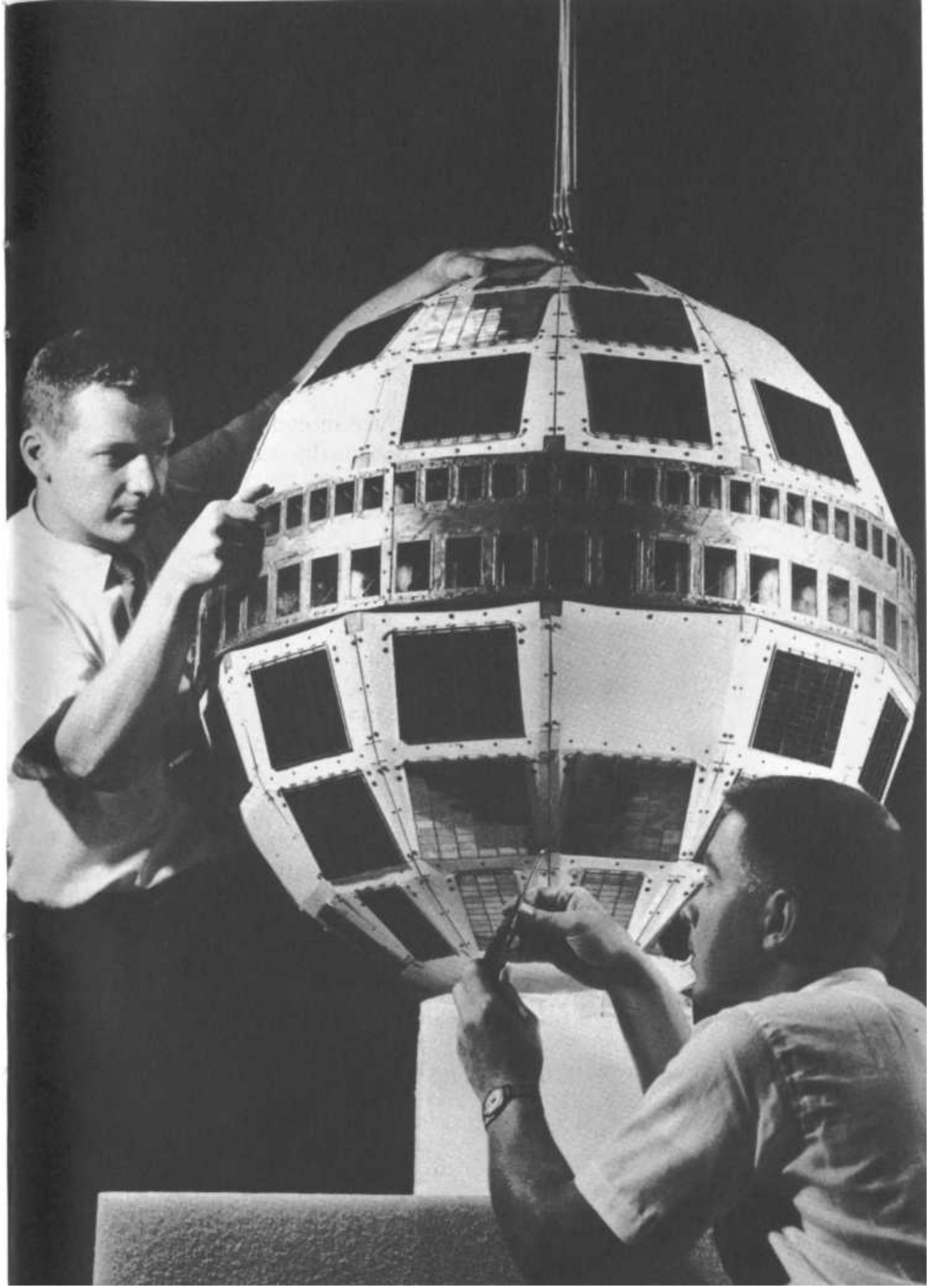
Experimenters everywhere are trying to make equipment with which the now wasted energy from the sun can be put to work. And they are trying in many ways to reduce the basic costs of the materials and processing.

In addition to their dramatic use in communication satellites. Bell Solar Batteries are used in the majority of experimental earth satellites as a long-lasting source of power for radio signalling. For example, signals from the Vanguard I satellite, launched in 1958, are still being received.

In 1955, solar cells were successfully used to power a rural telephone system outside Americus, Georgia. In the experiment, a solar power supply consisting of 432 silicon cells was placed atop a telephone pole, angled to get the utmost benefit from the sun, and connected to the rural telephone circuit. Excess current not needed for immediate use was fed into storage batteries to provide power at night and during periods of bad weather.

Other proposed uses include ...

... powering of seashore or offshore beacon lights
... powering mountain-top weather stations for unattended operation
... supplying power for portable radios
... an experimental Signal Corps helmet, with clusters of solar cells to power a walkie-talkie radio
... solar powered automatic adjustment of the iris in cameras
... solar powered flashlights, toys
... solar power for voltage on pipe lines to combat certain types of corrosion.



Bell Telephone Laboratories technicians prepare developmental model of a TELSTAR communications satellite.

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