SPACE POWER - STATIONARY SYSTEMS

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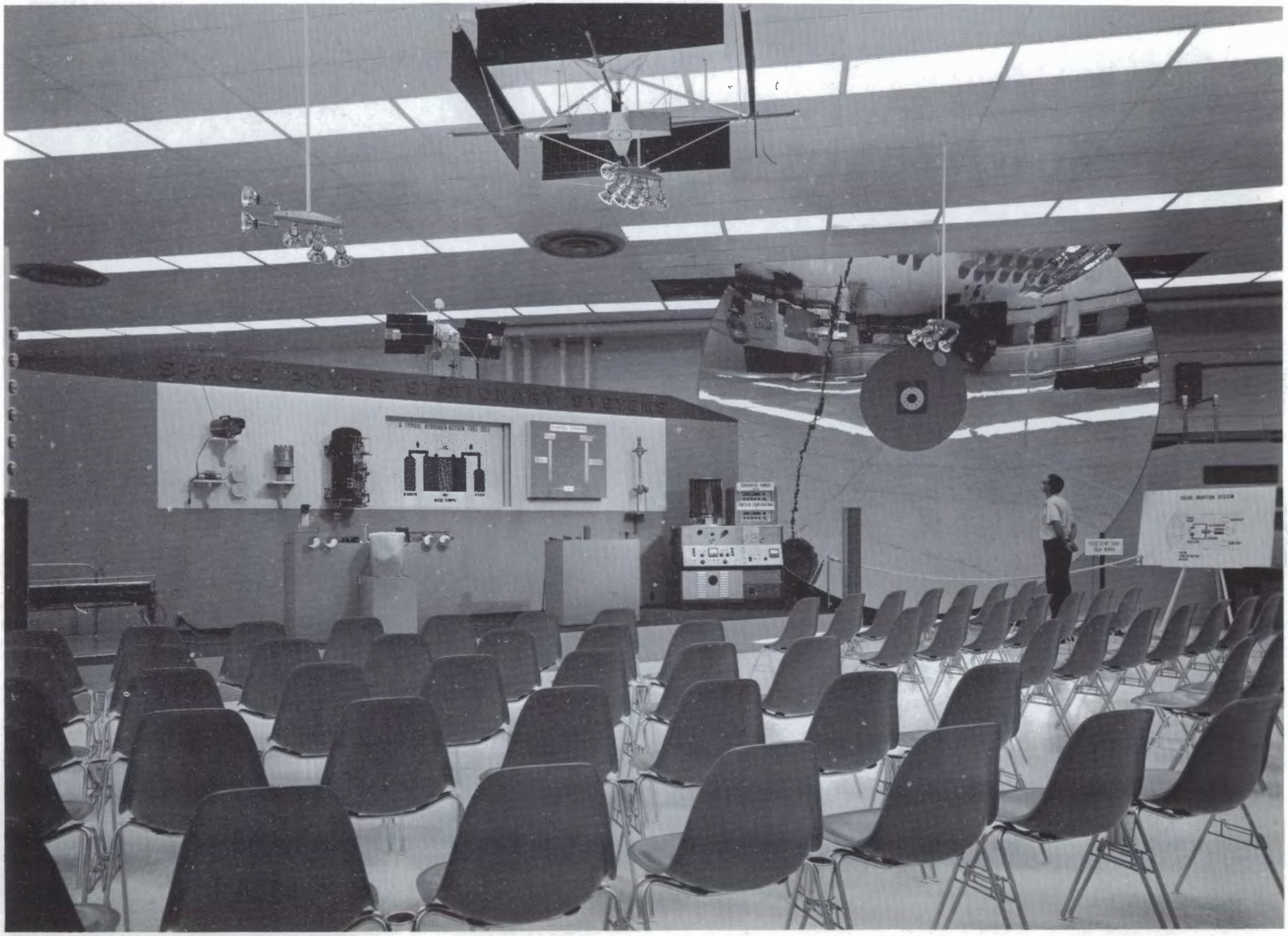
SPACE POWER STATIONARY SYSTEMS
A TYPICAL HYDROGEN-OXYGEN FUEL CELL

SPACE POWER - STATIONARY SYSTEMS

BATTERIES AND FUEL CELLS

There are many ways of producing electric power in space. At this stop we will talk about four of them: batteries, fuel cells, thermionic converters, and solar cells. These are names representing four entirely different concepts, but they do have one thing in common. Each of them is a method for producing electric power directly from an outside energy source. In the case of batteries and fuel cells, the energy comes from chemical reactions; in the case of the thermionic converter, it can come from a nuclear reactor; and in the case of solar cells, it comes directly from the Sun.

Everyone is familiar with batteries. Batteries like the one I am holding are used by almost everyone just about every day. Batteries are also commonly used in space. Almost every spacecraft flown to date has used batteries to provide onboard electric power. But these are special batteries; they are designed to meet the special needs of space. For example, batteries that we commonly use are designed to operate most efficiently at ordinary temperatures. Batteries for use in space may have to operate at extremes of temperature. Mariner II has shown us that the surface temperature of Venus can be as high as 800° F. We also think that the temperature during the Martian night will drop to 140° F below zero.

Let us now see what happens to our ordinary flashlight batteries if subjected to these extremes of temperature. I will take this battery with the paper removed and insert it into a small electric oven. The oven will be heated to about 750° F, approximating the temperature of Venus. The oven will take a few minutes to heat up, and while it is doing so, we can see what happens to another flashlight battery subjected to cold temperature. The bath in front of the table contains a mixture of dry ice and freon and is being held at a temperature of 110° below zero. I will now put the battery, which is running one of the small fans on the table, into the bath. As you can see, in a few seconds, the battery begins to fail and, at this point, is almost completely frozen. Also, in the bath is this type of new low-temperature battery. This battery was designed under contract to Lewis, and batteries like this one have operated at temperatures down to 140° below zero for times up to 100 hours. The battery right in the bath is running one of the small fans to the right of the table. Before the development of this battery, low-temperature batteries would operate for a maximum of only 36 hours at temperatures down to only 60° below zero.

You can see that, while I was talking, the battery we put in the small oven has come completely apart. Next to it in a similar oven also held at about 750° F is this type of high-temperature battery. This battery was designed by members of the Lewis staff. Batteries like it have run for 200 hours at temperatures up to 1000° F. The battery now in the small oven is running the small fan to the extreme right of the table. High-temperature batteries now in use would last for only a very few minutes at this high temperature. Thus you see that we now have the capability of providing electric power from batteries over a temperature span of 1200° F.

All batteries do have things in common. We could see this by examining part of an ordinary car battery. As you can see, it is made up of many metal plates. The chemical stored on these plates will provide all the electric energy that the battery will produce. When the battery is in operation, the space between the plates is usually filled with a fluid for the electrolyte which simply serves to complete an internal circuit. Unfortunately, chemicals stored on battery plates like this tend to be heavy. And since all spacecraft are weight limited, we would like to use chemicals that are lighter in weight and perhaps even more efficient. An ideal combination of chemicals would be hydrogen and oxygen, but these are gases and cannot be plated on electrodes, as is done in the battery.

A device for using these chemicals and others like them is called a fuel cell. On the chart we have a schematic diagram of a typical hydrogen-oxygen fuel cell (fig. 1). The gases, hydrogen and oxygen, are stored outside the cell and are fed in as needed. The fuel cell contains two electrodes. These provide sites for the chemical reaction and a metallic path for the conduction of electricity. The space between the electrodes is filled with an electrolyte as in batteries. Water, which is the product of the chemical reaction between hydrogen and oxygen, must be continuously removed from the cell when it is operating.

Fuel cells have provided power for some of the Gemini missions; they have also been approved for use on the Apollo. But for future space applications, we would like fuel cells that are even more efficient and run for longer times. The key to getting these improvements lies in the electrodes that are used. I have here an electrode developed under contract to Lewis. As you can see, it is thin, flexible, and light. It is also efficient. Electrodes like it have been run continuously for over 3000 hours. To make a fuel cell with these electrodes, you simply take two of them and place a sheet of porous asbestos which has been impregnated with the electrolyte between them to form a thin sandwich, and, if hydrogen is applied to one side and oxygen to the other, electricity would be produced. To demonstrate how a fuel cell operates, we can use the two gas containers on the table. One contains oxygen, the other hydrogen. Over the face of each we have placed an electrode, and over the face of one of them we have also placed a sheet of asbestos which has been soaked with an electrolyte. If I simply bring the two into contact, as you can see by the motion of the small fan on the table, we are producing electricity.

Practical fuel cells would look somewhat different from this. For example, the gas compartments would be much smaller. Typically, they are about 0.10 inch thick. This is an example of a practical hydrogen-oxygen fuel cell. I am sure you can all see how thin it is. Unfortunately, single cells like this produce only about 1 volt. To bring the voltage up to where it can be used, we must take many single cells and connect them in series. Once this is done, we stack them as has been done with the stack on the stage to form a very compact package containing many cells. Having this, we add auxiliary equipment to control temperatures and the gas flow rates to form a complete fuel cell power system. The system on the stage, when operating, will produce 2000 watts of useful electric power and will continue to produce it for as long as hydrogen and oxygen are fed in. We believe that the principles used in development of low- and high-temperature batteries and in the development of the fuel cells will find many applications in the commercial production of electric power.

THERMIONICS

The thermionic converter is very similar to this vacuum tube, which is the type used in many radio and television sets. As many of you know, inside the tube a filament is heated to a very high temperature. Electrons are then emitted from the filament and collected by a plate located a short distance away. A thermionic converter operates in much the same way (fig. 2). It also consists of two metal electrodes separated by a small gap. Heat is supplied to one of these electrodes, which we call the emitter. As the emitter temperature increases, electrons in the metal gain sufficient energy and are in effect boiled out of the metal. These electrons, represented by the orange lights, move into the evacuated gap and a small fraction reach the second electrode - called the collector. The collector must be cooled to maintain it at a lower temperature than the emitter. Useful power then is delivered to the load as the electrons return to the emitter through an external circuit.

It has been found that the addition of cesium vapor to the space between the electrodes, represented by these blue lights, increases the number of electrons reaching the collector. This, then, results in a substantial increase in the power delivered to the load. As a result, today all high performance converters use cesium vapor.

I have here on stage some actual parts of a thermionic converter to show the difference between the way it looks and the way a vacuum tube looks. As you can see, in this case the emitter is cylindrical and is connected to the support structure. The emitter then fits inside the collector assembly and, thus, we have a fairly simple and direct method of converting heat into electricity. However, as we will show in this next demonstration, extremely high temperatures are required.

Here on stage we have an operating thermionic converter inside this vacuum bell jar. Its emitter temperature is displayed here in degrees Fahrenheit, and the power generated is given here in watts. You can see at the present time that we are at about 1800° F on the emitter and we are generating no power, even though this temperature is well above the temperature of a heating element in an electric range. We will now increase the emitter temperature. You might observe the increase in brightness as we do this. You can see that at about 2000° F we are just generating a small amount of power; as the temperature increases to about 2500° F, the power generated is up to about 12 watts. At this time we are approaching the melting point of steel, and, for this reason, we require a refractory metal such as tungsten for the emitting electrode. The temperature is being increased further, and you notice that the power is increasing rapidly so that now, at about 3000° F on the emitter, we have about 40 watts generated. This is over three times the amount of power generated at 2500° F. This, then, demonstrates that the thermionic conversion process is strongly dependent on emitter temperature and that temperatures of at least 2000° F are required to generate even small amounts of power. The key, then, to thermionic conversion is the development of a high-temperature heat source.

The nuclear reactor is one such heat source which would be particularly attractive for high temperature, high power, long-time space missions. We have here a very simple model of a reactor core, which will show one possible way of combining the nuclear fuel with the thermionic converters. In this case, the core consists of a large number of rods - called fuel elements. Each fuel element, in turn, consists of a number of segments and these segments will then contain both the nuclear fuel and the thermionic converter. This larger model will show how each segment would be constructed. The innermost cylinder of each segment would be the nuclear fuel, which is a heat-producing material. This fuel then is contained in a metallic cylinder, which also serves as the emitting electrode for the thermionic converter. The collector is then placed around the emitter and separated from it by about 0.0001 inch. In this gap, then, we have the cesium vapor. Thus, in a single device, heat is generated and converted directly into electricity. Each one of these segments would be made in a similar manner, and we would construct the fuel element by placing a number of converters end to end in a metal tube, much like batteries in a flashlight case. A typical fuel element this size would contain about 15 converters and generate about 2000 watts of power.

Mounted in this test fixture is an actual thermionic fuel element. As you can see, it is much more involved than this simple model used for this demonstration. A reactor core this size, which is about 2 feet high by a little more than 1 foot in diameter, would contain about 500 of these fuel elements and would generate about 1 million watts of electricity. This is roughly equivalent to about 1300 horsepower. Thus, we have a large amount of power generated in a relatively small volume. This is one of the reasons we are so interested in nuclear thermionics for space power applications. Incidently, this 1 million watts is sufficient to light about 1000 homes; in fact, studies have shown that thermionics may be of interest for future commercial power generation.

Before we could actually build a reactor core such as this, a number of problems have yet to be solved which are concerned mainly with the very high temperatures involved. Research is being conducted to improve the power output of converters, which may allow us to operate at lower emitter temperatures. We are also attempting to extend the life of the converters and improve their reliability. In addition, we are looking at the problems associated with the very high temperature in nuclear fuels. Much of this work is being conducted both here at Lewis and by our contractors.

SOLAR CELLS AND THE SOLAR COLLECTOR

This tiny device is a silicon solar cell. It converts sunlight directly into electricity and has been used to provide primary electric power to nearly every NASA spacecraft flown. These cells are made by first growing a single crystal ingot of the element silicon. Wafers about the diameter of a half dollar and a little thinner than a dime are sliced from the ingot and processed to form the finished cell. A wafer this size yields two of these cells. These cells produce electricity by absorbing sunlight into the silicon atoms, which release electrons that move to the surface of the cell where they are collected by a grid (fig. 3). These electrons provide the flow of current which produces electric power.

Now we all know that the silicon cell works well in space, but what are its principal disadvantages? One is its size, which is limited by the fact that it is very difficult to grow a good single crystal ingot that has a diameter much larger than that shown in this sample. Since each cell produces only a few hundredths of a watt, thousands of cells are required to make a solar cell panel. To illustrate the magnitude of the problem arising from the cell's size, suspended over the backdrop is a one-quarter scale model of the OGO, or Orbiting Geophysical Observatory, spacecraft. The two solar cell panels on the full size spacecraft produced 500 watts of electric power and contained almost 33 000 solar cells. I think you can imagine the degree of difficulty encountered in connecting and mounting that many cells. Nevertheless, solar cell panels such as these can easily provide the relatively low power requirements of present day spacecraft. However, future missions will require power levels which are 50 to 100 times greater. These higher power levels will require so many cells that cell size and array fabrication costs will become important considerations. Another disadvantage of this silicon solar cell is that it is fragile, and therefore it must be mounted on a relatively heavy, semi-rigid shock-absorbing substrate.

I think the improvements we seek are obvious. First, we would like a large cell that would minimize the number of cell-to-cell interconnections. Second, we would like a flexible cell that would reduce or eliminate the need for any array mounting structure. To meet these requirements, this Center and our contractors are developing this entirely different type of cell called a cadmium sulfide thin-film solar cell. It is much larger than the silicon cell and, since it is made by depositing a very thin layer of cadmium sulfide on a flexible backing, its manufacturing process is not strictly limited to size. In addition, the cell is flexible and rugged; it can be bent, rolled, and tugged with no adverse affects. In forming arrays of these cells, the cells could be connected directly to each other and thereby eliminate nearly all the structure normally associated with the solar cell array. To illustrate this point, suspended from the ceiling overhead is a model of what we think a thin-film solar cell array might look like. It will now be deployed. The sheets of simulated cells are being pulled from the rollers by the tubes in the same fashion as you would pull down a window shade in your home. All four tubes are stored as flat tapes on a single drum and form into tubes as they leave the cruciform form structure. This deployment technique takes advantage of the flexibility of the thin-film cell. If this array contained real cells and were deployed in space, it would produce about 1200 watts of power from its area of 240 square feet. Another feature of this type of array is that array panels can be easily retracted. The motor is taking up slack on the central storage spool. The wires and some of the support structure are necessary to assist deployment on Earth and would not be required in space. We estimate that a flight model this size would weigh about 40 pounds, approximately one-half the weight of this unit.

Located on this side of the stage is another model of a cadmium sulfide thin-film array. This array, however, contains active cadmium sulfide cells and is formed by joining the cells directly to each other. If we could have a little sunshine, power from the array would operate the tape recorder and television set.

The solar Brayton system is another method for converting the Sun's energy into electricity. In that system, which was discussed in detail at another stop, a large mirror concentrates the Sun's energy to provide a source of intense heat. To explore the problems of fabricating the large mirrors required for those systems, Lewis engineers built this 20-foot diameter prototype. It consists of 12 sectors bolted together. One such section is suspended from the ceiling to your immediate left. Each sector is made from a 1-inch-thick flat magnesium plate, and pockets are machined into the back, leaving the ribbed structure, which provides stiffening with minimum weight. The machine sectors are then formed into the final curved surface. A layer of epoxy resin is applied to provide a smooth surface on which to deposit the reflecting layer of aluminum. The large black device below the sector is used to check the optical characteristics of each sector and of the completed mirror. To demonstrate the concentrating ability of the mirror, a small tungsten plate, suspended from the ceiling and located at the mirror focal point, will be heated from room temperature to about 1900° F in a matter of a few seconds. The instrument located in the center of the mirror records temperature of the plate in hundreds of degrees Fahrenheit. For this demonstration, only two sectors of the mirror will be illuminated, since we do not have a light source large enough to illuminate the entire mirror. The tungsten plate is actually heating up much faster than the temperature can follow, and as a result, the temperature recorder will stop rather abruptly when it catches up with the temperature of the plate. Incidently, the weight of this mirror is about 300 pounds. There, we have about 1900° F.

Our work on this prototype has shown us that it is possible to build large concentrating mirrors that meet the weight and accuracy requirements of the solar Brayton system.

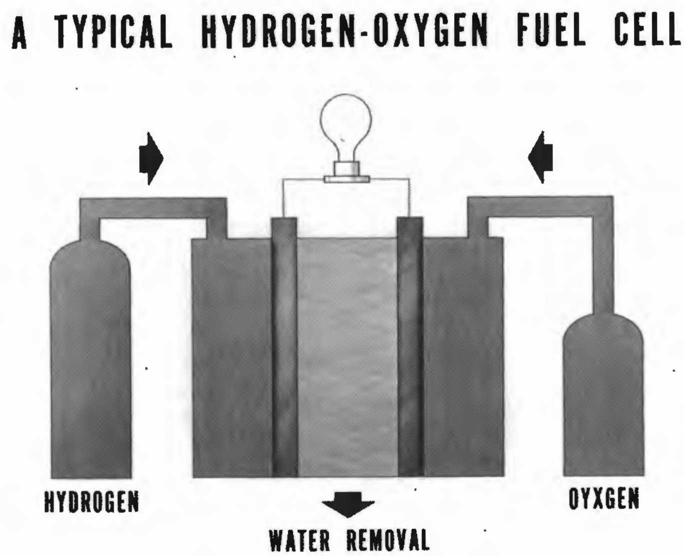

Figure 1

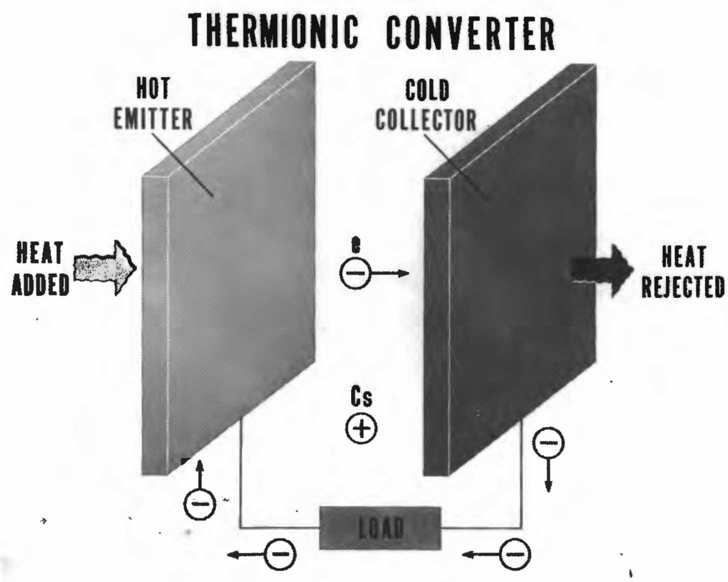

Figure 2

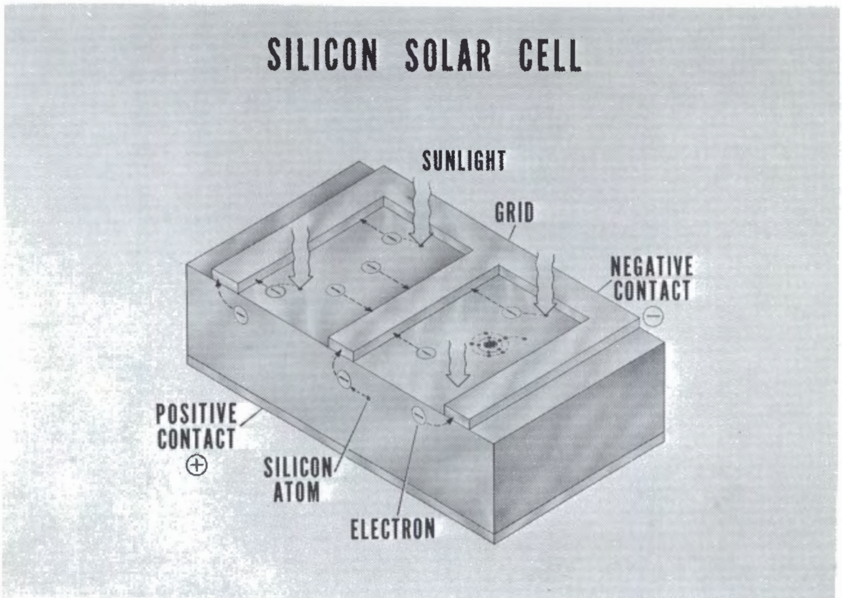
SILICON SOLAR CELL
SUNLIGHT
GRID
NEGATIVE CONTACT
POSITIVE CONTACT
SILICON ATOM
ELECTRON

Figure 3

NASA
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NASA
C-66-3861

NASA
C-66-3859

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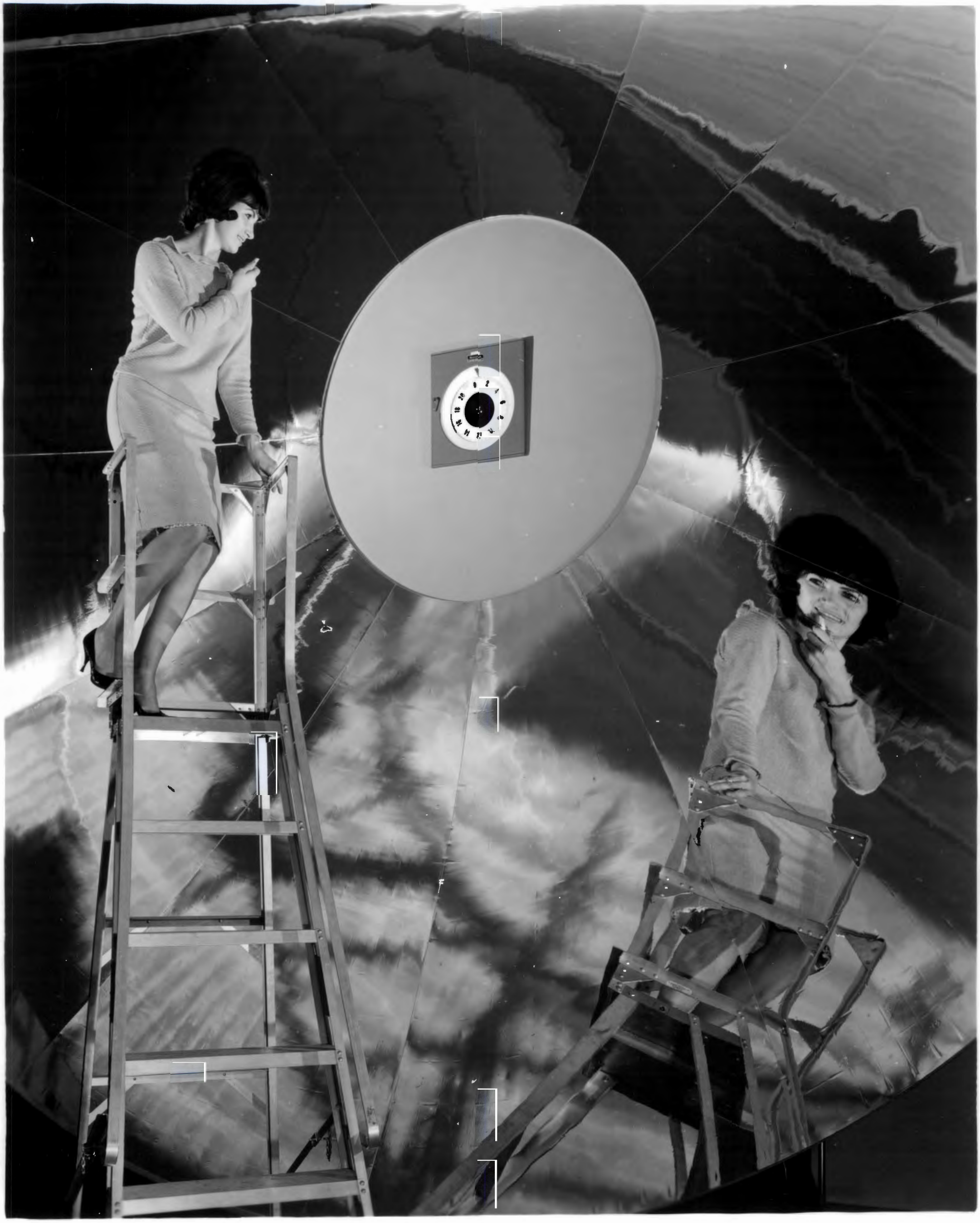
C-66-3862

NASA
C-66-3854



NASA
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NASA
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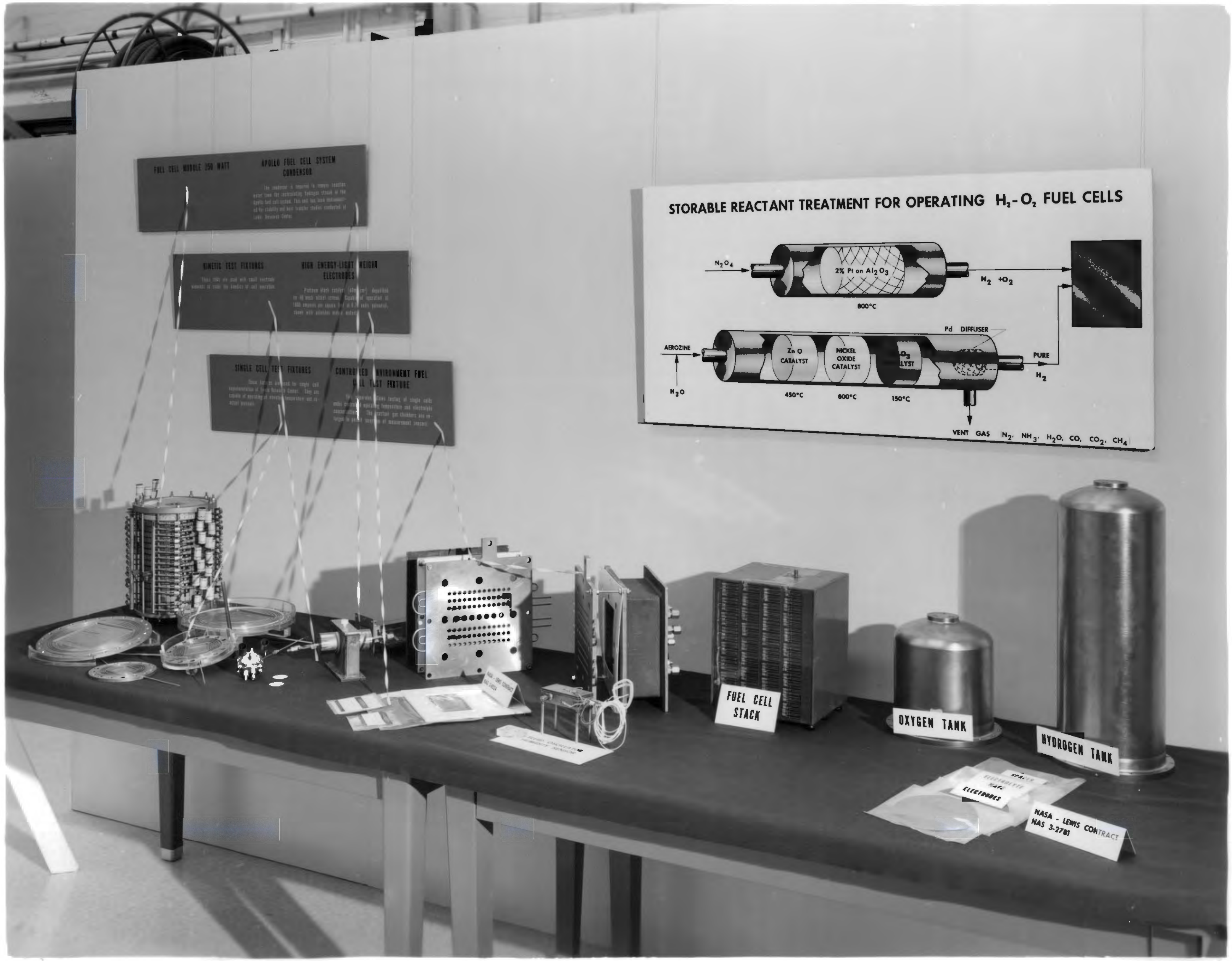

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