ELECTRIC PROPULSION

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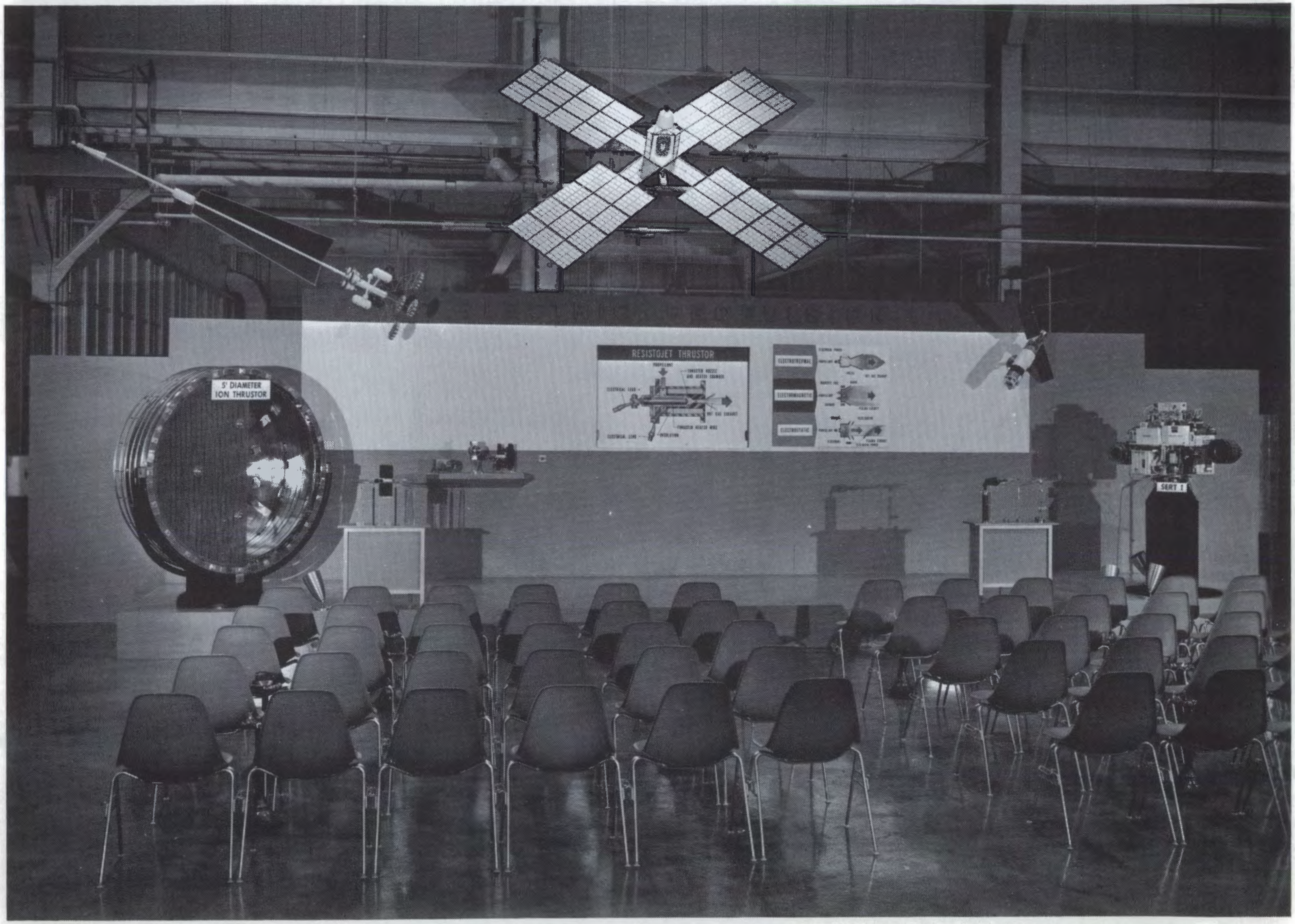
5' DIAMETER ION THRUSTOR
RESISTOJET THRUSTOR
PROPELLANT
THRUSTER NOZZLE AND HEATER CHAMBER
ELECTRICAL LEAD
HOT GAS EXHAUST
TUNGSTEN HEATER WIRE
INSULATION
ELECTRICAL LEAD
ELECTROTHERMAL
ELECTROMAGNETIC
ELECTROSTATIC
SERT I

ELECTRIC PROPULSION

All space propulsion schemes that are either used at present or under serious consideration operate on the same basic principle. Propellant mass is ejected with a high exhaust velocity, producing a thrust in the opposite direction. Electric rockets, or thrustors, can produce much higher exhaust velocities than ordinary chemical rockets, but their thrust levels are lower. These high exhaust velocities permit a given mission to be accomplished with less propellant mass than is required for a chemical rocket. This reduced propellant requirement, and, hence, increased payload capability, is the outstanding advantage of electric propulsion.

There are three general types of electric thrustor. Research on all three types has been or is being conducted at this Center. The electrothermal type (fig. 1) uses electric power to heat a propellant, similar to the way that combustion heats the propellant in a chemical rocket. In either case, the hot gas is expanded through a nozzle to obtain a high exhaust velocity. The arc jet, in which an electric arc is used to heat the propellant, is one type of electrothermal thrustor. The technology gained in studying the arc jet has been useful for designing hypersonic wind tunnels and has led to the development of the magnetoplasmadynamic, or MPD, thrustor, which I will describe later.

The second type of electrothermal thrustor is the resistojet (fig. 2). Some of the early research on the resistojet was conducted at this Center. In this thrustor, a resistance heating element or hot wire is used to heat the propellant. The resistojet is simple, efficient, and reliable. The research effort on this thrustor has been completed, and it is the one electric thrustor that has already been used in a practical application - the station keeping of a satellite. This is an actual resistojet. It has a thrust level of about 1/1000 of a pound with an input power of about 5 watts and uses an ammonia propellant.

For future applications, the other two types of thrustor produce higher exhaust velocities.

The second general type of electric thrustor is the electromagnetic type (fig. 1). The electromagnetic thrustor uses the interaction of a current and a magnetic field, similar to that used in many electric motors. The moving conductors of the current in an electric motor are copper wires. In an electromagnetic thrustor, the conductor is a plasma or ionized gas. If an electron is removed from an atom of propellant, the atom no longer has an equal number of electrons and protons, and is called an ion. A gas composed of ions and electrons is called a plasma and can conduct an electric current similar to the way a copper wire does.

(Demonstration - electromagnetic thrustor principle)

If we let this carbon ball represent the electrically conductive plasma, we can easily see the effect of a current passing through a plasma in the presence of a magnetic field. The current comes from one support rail, through the ball, into the other support rail. The magnetic field is produced by the large permanent magnet. This combination of current and magnetic field accelerates the ball - or plasma.

This general acceleration principle has been used in many types of electromagnetic (or plasma) thrustor. Some of these have developed into potentially attractive thrustors. Most are being used in various plasma physics experiments.

The most promising electromagnetic thrustor is the MPD or magnetoplasmadynamic arc type (fig. 3). It resembles an arc jet in general construction, with the current passing between an anode and a cathode. It operates at a much lower propellant pressure than an arc jet, though, so that electromagnetic forces proved the dominant thrust-producing mechanism. The magnetic field can either be due to the current between these two electrodes or, as shown here, it can be produced by a separate field coil.

This particular version of MPD thrustor (show model) operates over the range from 10 to 30 kilowatts and has reached an exhaust velocity of nearly 30 miles per second, which is definitely in the range of interest for electric propulsion. Later you will see this size of thrustor operating in the smaller of the two large vacuum chambers to your right.

The MPD thrustor (show model) has also been built in this smaller size, suitable for satellite station keeping. In either the large or small size, the advantage of the MPD thrustor (in addition to reasonable efficiency) is the simplicity of associated electrical circuitry. It does not require much more than you see here, plus a source of electric power. Considerable development remains, however, before the MPD thrustor will be ready for use in space.

The last general type of electric thrustor is the electrostatic type, which (outside of the resistojet) is the most developed (fig. 1). The propellant is also ionized in the electrostatic thrustor, but the ions are accelerated without mixing in the electrons with them. After the ions are accelerated, the electrons must be added to neutralize the beam and avoid building up a charge of electrons on the space vehicle which would interfere with thrustor operation.

(Demonstration)

Simply stated, the operating principle of the electrostatic thrustor is that like charges repel and unlike charges attract. The ion source has many like-charged ions which repel each other. The accelerator grid is charged with unlike charges, or electrons. This combination serves to eject the ions with a high exhaust velocity. In this model, the ball represents an atom and becomes charged by contacting this high-voltage metal conductor. The charging process, of course, corresponds to ionization. Having been charged, it is then repelled from the like-charged metal conductor and travels up these nonconducting rails. This second electrode corresponds to the accelerator grid. In an electrostatic thrustor, the charged particles leave the thrustor after acceleration. Here, we want the ball to return and repeat the process; therefore, the second electrode is placed close enough to discharge the ball as it goes by. This electrode is also pivoted to show the electrostatic force between it and the ball.

There are different ways of producing ions. One is the contact ionization method (fig. 4) where a cesium propellant atom loses an electron (and thus becomes an ion) by passing through porous tungsten. The tungsten has to be hot enough to boil off the ions. This heating power is the largest loss in the contact-ionization thrustor.

Contact-ionization thrustors appear best suited for low-thrust applications. This thrustor (show model) is similar to the sketch, but the entire thrustor is in the small cylinder at one end. The larger cylinder contains the propellant tank, and the box contains the electrical equipment necessary to supply the various voltages and currents needed. This is the size needed for station-keeping duty on a satellite, and its total power input is less than 20 watts.

For larger sizes of electrostatic thrustors, electron bombardment appears to be a more efficient means of producing ions (fig. 5). Ions are produced in this chamber by striking propellant atoms with energetic electrons which are emitted from this hot cathode. This type of thrustor, which was invented and developed at this Center, has already been tested in space for a short time on the SERT I payload.

This (show model) is a duplicate of the SERT I payload. The letters SERT stand for Space Electric Rocket Test. SERTI, managed by this Center, was launched July 20, 1964 on a ballistic trajectory over the Atlantic Ocean. It was the first time that an ion engine of any type had been successfully operated in space. After launch, the two ion engines were deployed as shown on the duplicate payload. The rest of the payload consists of instrumentation, electronics, and batteries. During the flight, the spacecraft was spinning. The ion thrustors were mounted so that their thrust would change the spacecraft spin rate. Measurements made during the flight conclusively proved that neutralization was not a problem and that an ion engine can generate thrust in space.

The SERT II vehicle, shown here in a one-tenth scale model (show model), is our next step in the development of large electrostatic thrustor systems. The Agena second stage will be orbited as part of the vehicle, which is the reason for the chemical rocket components in this model. The thrustor and electronics payload, which will be designed and built by Lewis, is mounted at the front of the vehicle. The SERT II flight, which should be launched late in 1968, is intended to demonstrate the long-life durability of electric propulsion systems in a space environment.

In the more distant future, electric propulsion may be used for instrumented probes and for manned interplanetary missions. This model (show manned Mars vehicle) assumes the use of a large nuclear-electric power source of the type discussed at the Space Power stop. The actual vehicle would be about 400 feet long and carry 8 men on a round trip to Mars. In the same way that we cannot use electric propulsion to take off from Earth, we cannot use it to land on Mars. The large vehicle would remain in orbit about Mars while small chemical rockets would be used for the actual landing.

Thrustors for an early electrically propelled interplanetary probe could be only a little larger than the thrustor tested on SERT I. Later applications will require larger units, such as the large thrustor here which can produce about 1 pound thrust and use about 150 kilowatts of electric power. A portion of the accelerator grids has been cut away to show the electron-bombardment discharge chamber, where the ions are produced. Later, you will see an operating electrostatic thrustor of this size in the larger of the two vacuum chambers in this room.

The two chambers in this room - 15 feet in diameter by 60 feet long, and 25 feet in diameter by 70 feet long - are the largest of our electric-propulsion facilities, but by no means our only ones. We have a number of smaller chambers in various buildings around the Center. These smaller chambers are used in a variety of programs, only part of which are directly concerned with propulsion.

An example of one of these related programs is the simulation of the solar wind with an MPD thrustor (fig. 6). The solar wind is merely a flow of high-energy charged particles which emanate from the sun. In the vacuum facility to your right, you will see the plasma jet from an MPD thrustor impinging on a model of the Earth. This model of the earth encloses a coil which produces a magnetic field similar to the magnetic field of the Earth. Bands or belts of luminous plasma are formed which are suggestive of the Van Allen belts actually found around the Earth. Currently we are making measurements on this plasma to try to determine the cause of the distinct band. The discovery of the cause of these bands may then lead to an explanation for the Van Allen belts.

You will now see the demonstrations in these large vacuum chambers.

(Demonstrations - $1\frac{1}{2}$ Meter Thrustor and Solar-Wind Simulation)

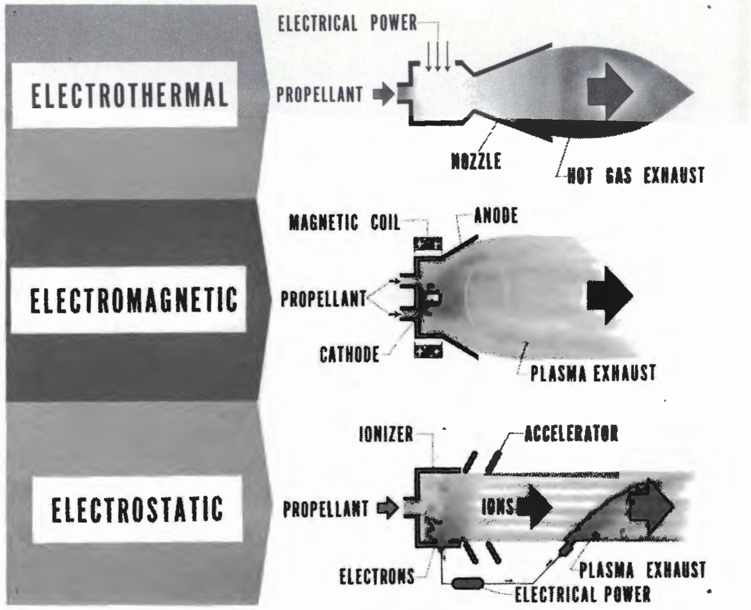

Figure 1

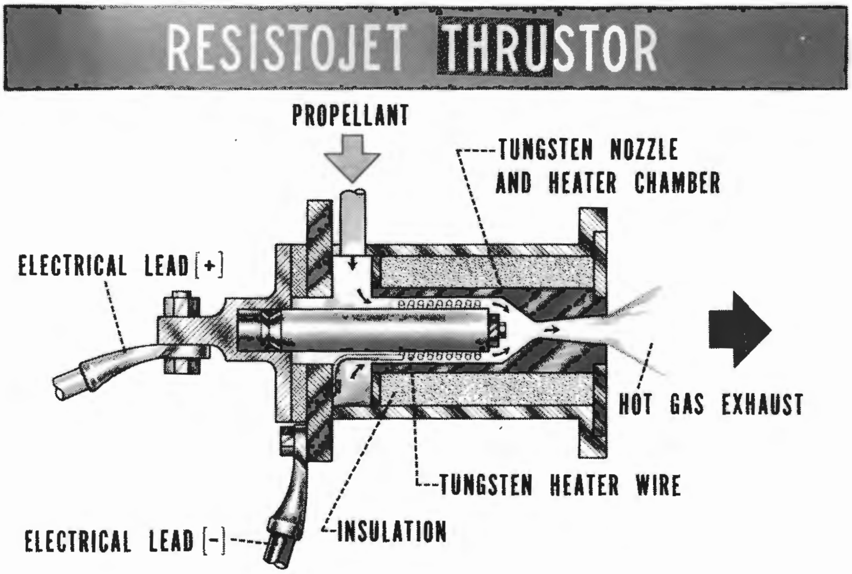

Figure 2

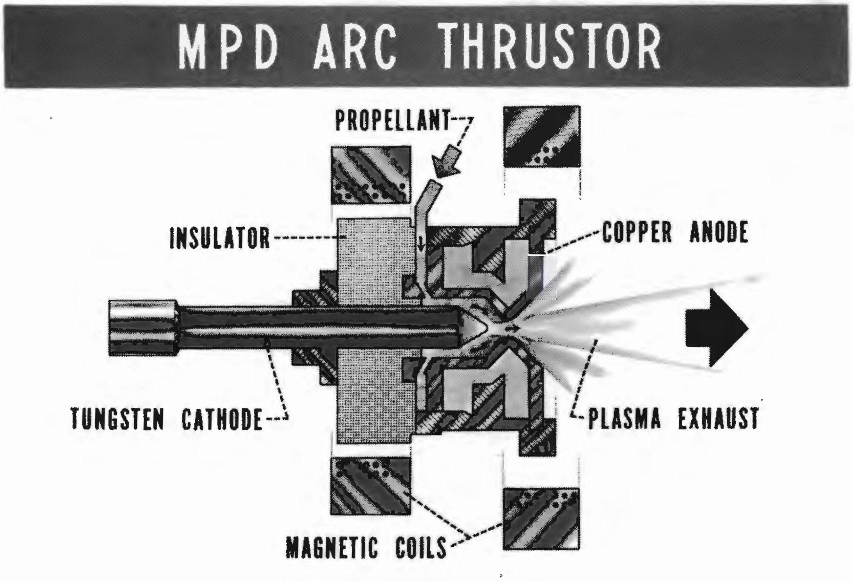

Figure 3

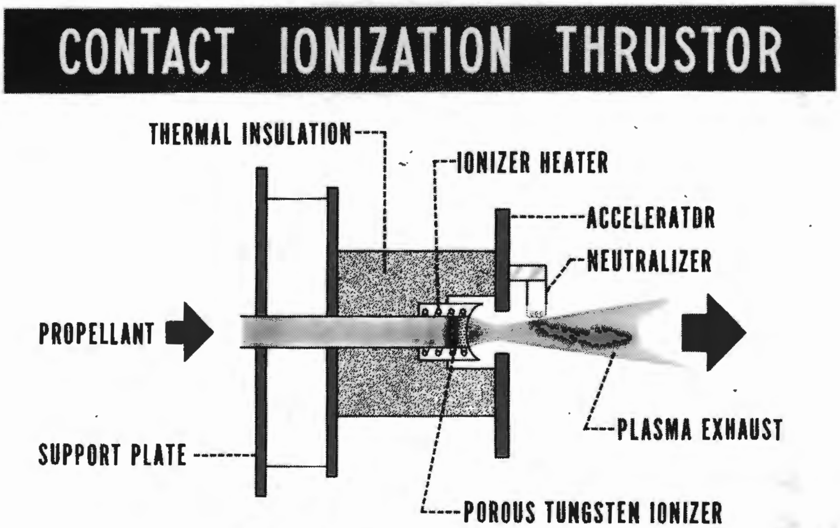

Figure 4

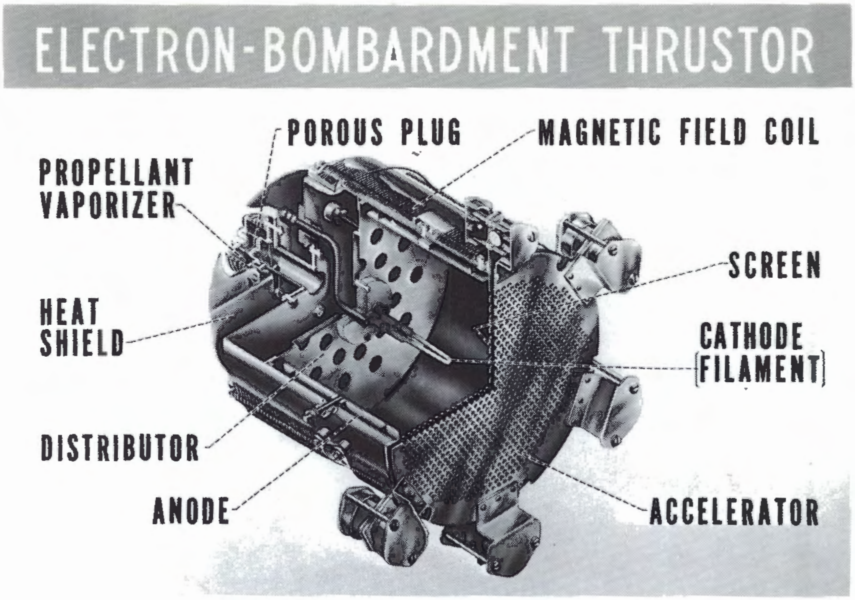

Figure 5

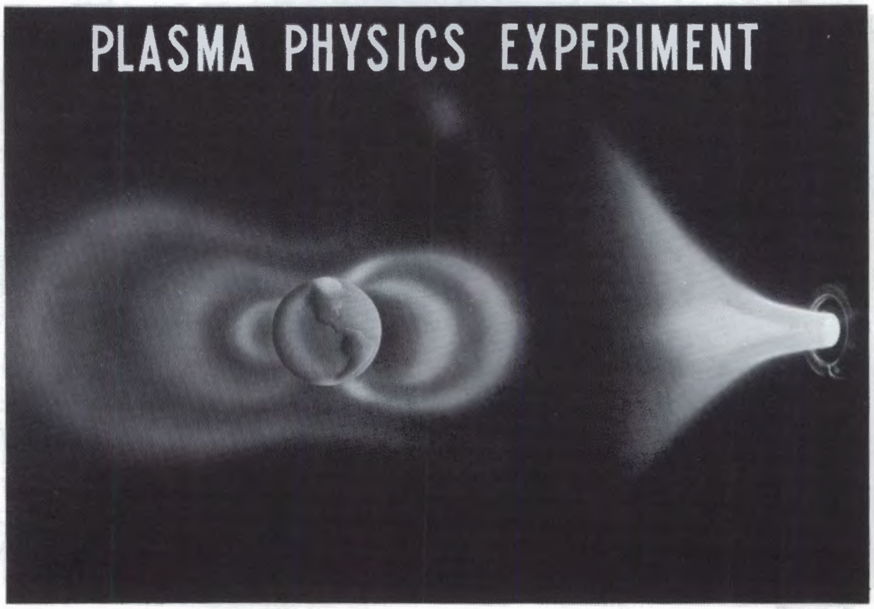

Figure 6

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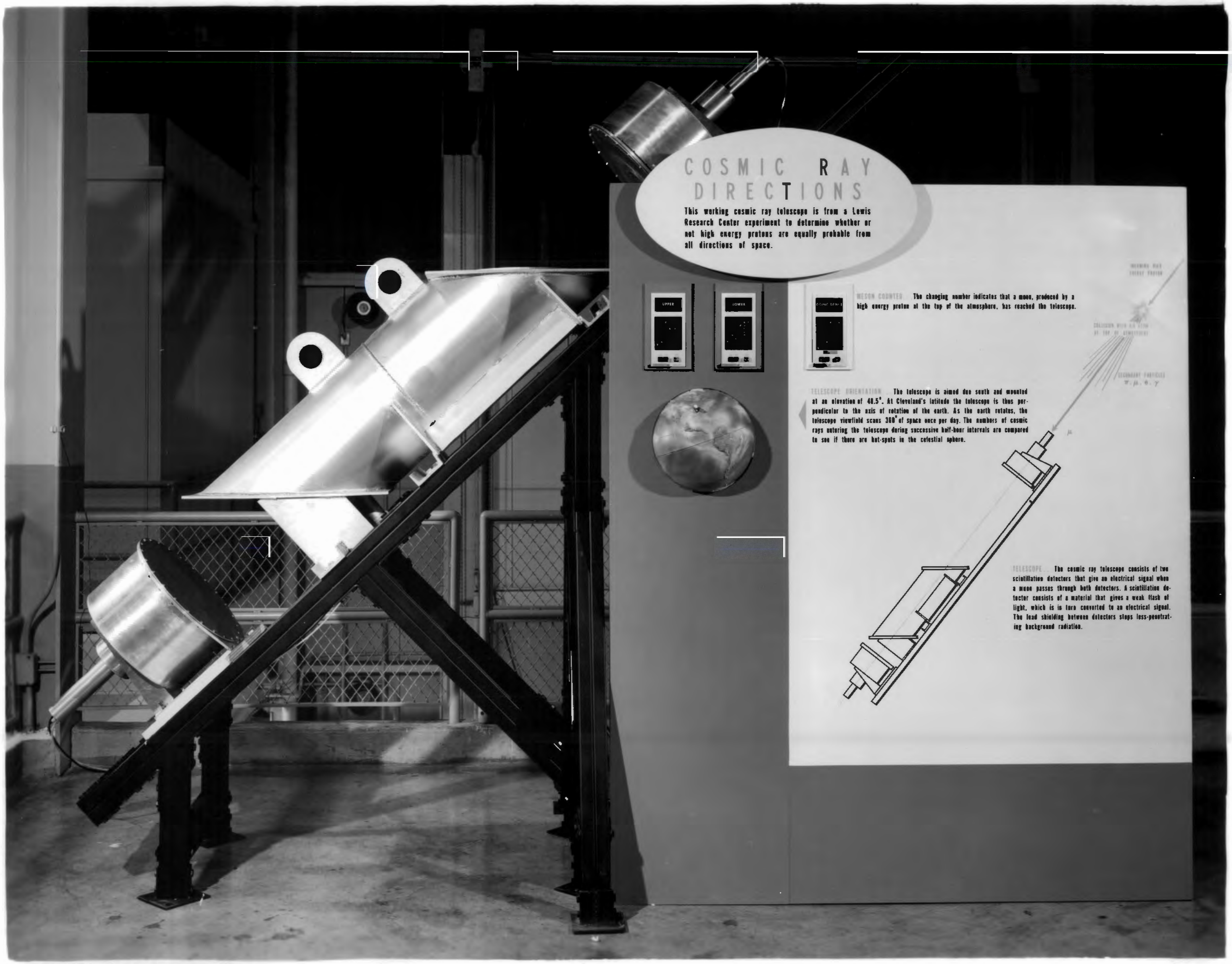

COSMIC RAY DIRECTIONS

This working cosmic ray telescope is from a Lewis Research Center experiment to determine whether or not high energy protons are equally probable from all directions of space.

MESON COUNTER . The changing number indicates that a muon, produced by a high energy proton at the top of the atmosphere, has reached the telescope.

TELESCOPE ORIENTATION . The telescope is aimed due south and mounted at an elevation of 48.5°. At Cleveland's latitude the telescope is thus perpendicular to the axis of rotation of the earth. As the earth rotates, the telescope viewfield scans 360° of space once per day. The numbers of cosmic rays entering the telescope during successive half-hour intervals are compared to see if there are hot-spots in the celestial sphere.

TELESCOPE .. The cosmic ray telescope consists of two scintillation detectors that give an electrical signal when a muon passes through both detectors. A scintillation detector consists of a material that gives a weak flash of light, which is in turn converted to an electrical signal. The lead shielding between detectors stops less-penetrating background radiation.

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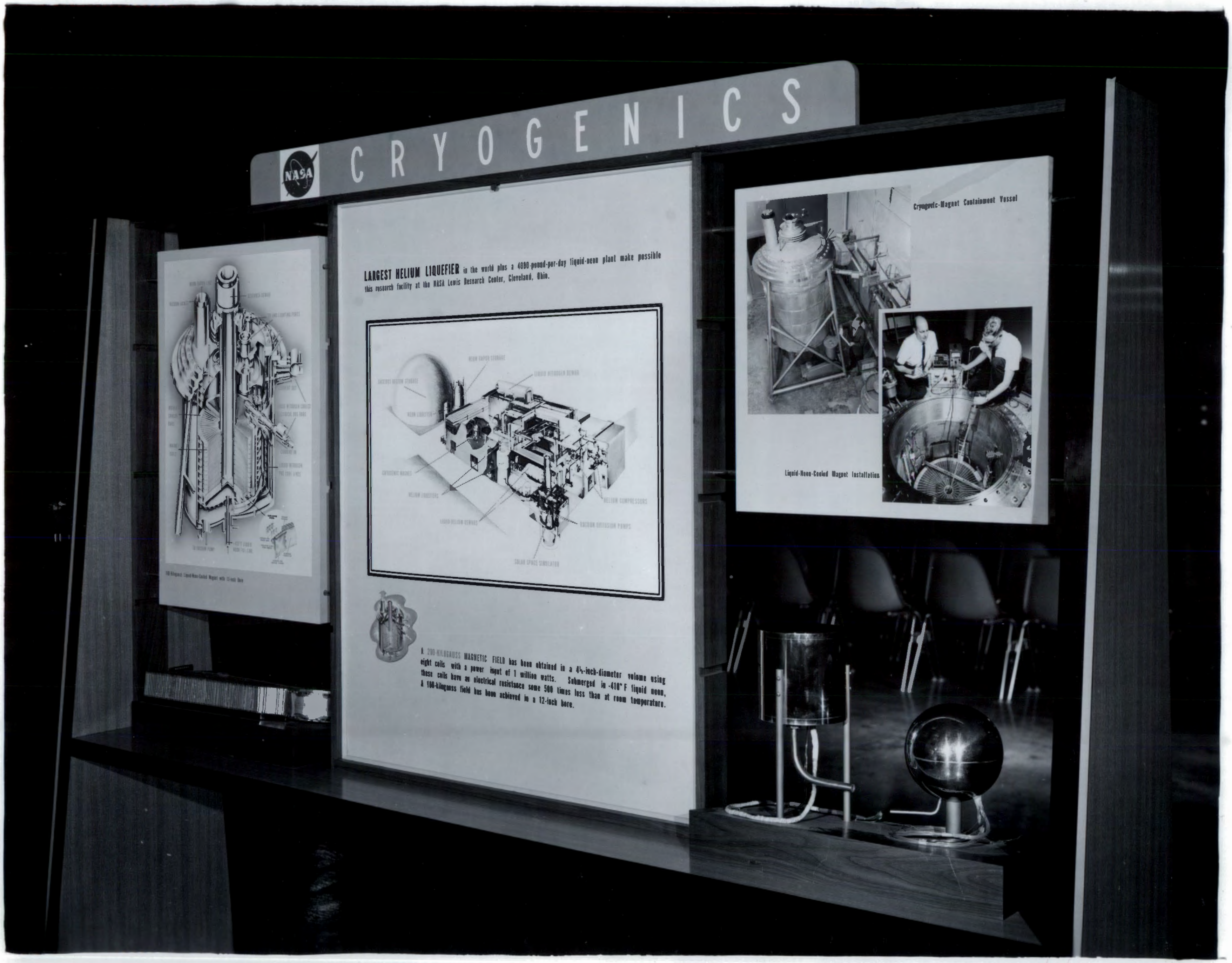

LARGEST HELIUM LIQUEFIER in the world plus a 4000-pound-per-day liquid-neon plant make possible this research facility at the NASA Lewis Research Center, Cleveland, Ohio.

A 200-KILOGAUSS MAGNETIC FIELD has been obtained in a 4½-inch-diameter volume using eight coils with a power input of 1 million watts. Submerged in -410° F liquid neon, these coils have an electrical resistance some 500 times less than at room temperature. A 100-kilogauss field has been achieved in a 12-inch bore.

NASA
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Nearly 60 miles of superconductive niobium - tin ribbon are wound on 22 coil forms and combined with 14 copper energy sinks to make up the 000- pound magnet.

This superconductive niobium - tin ribbon will carry as much current as this copper conductor.

SUPERCONDUCTIVE MAGNET

Lewis Research Center programs require the intense magnetic fields provided by superconductive magnets. This new 15 Tesla (150,000 Gauss) magnet will permit investigation of superconductive phenomena at -450° F. Information from this research should find application in future space power generation and propulsion systems. Once energized, a superconductive magnet requires no electrical energy to maintain its field.

Skill and great care are required in the fabrication, coil winding, and inspection of the various magnet components.

Liquid helium surrounding the magnet suspended inside the vacuum-jacketed vessel maintains temperatures at which the windings are superconductive.