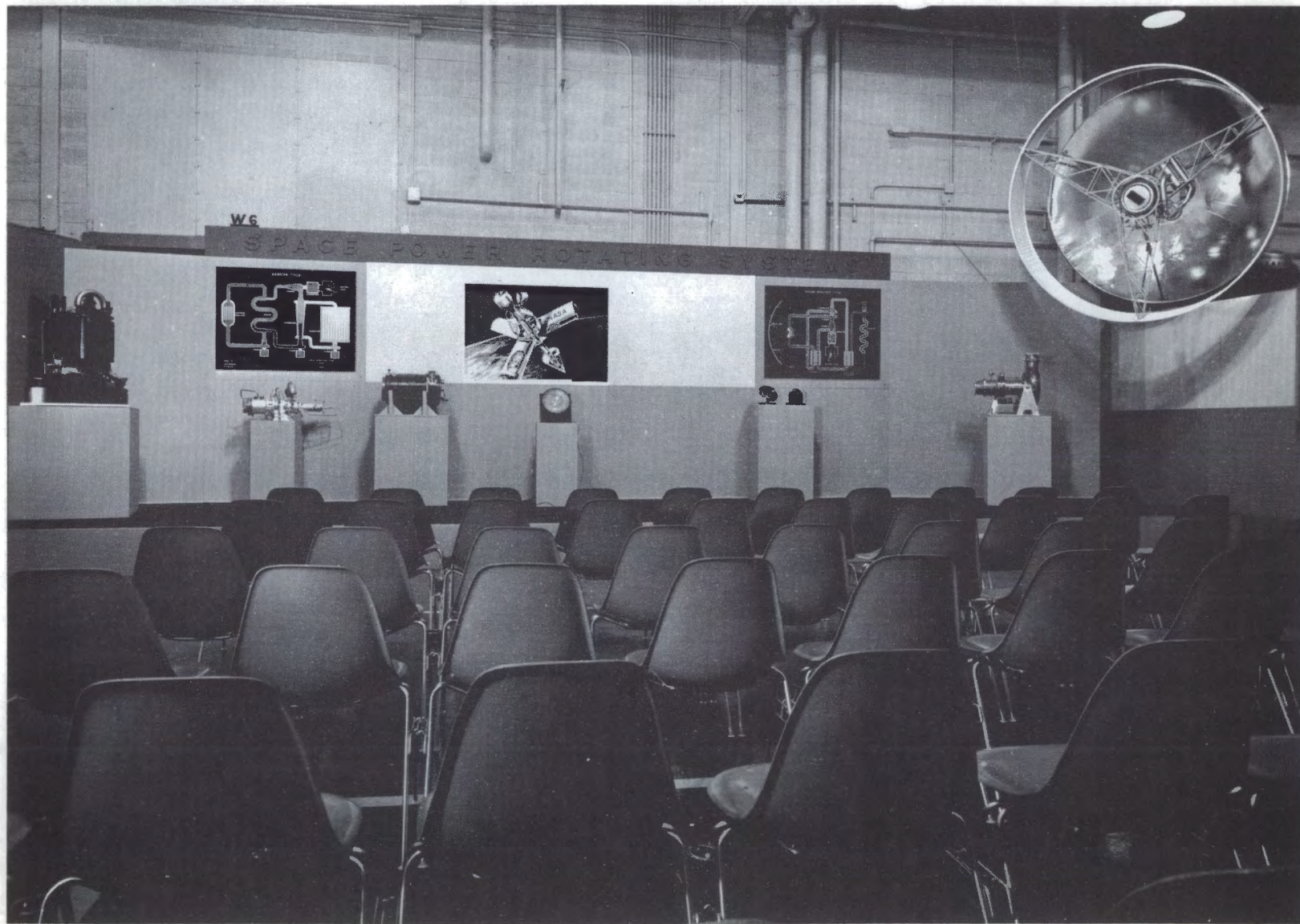


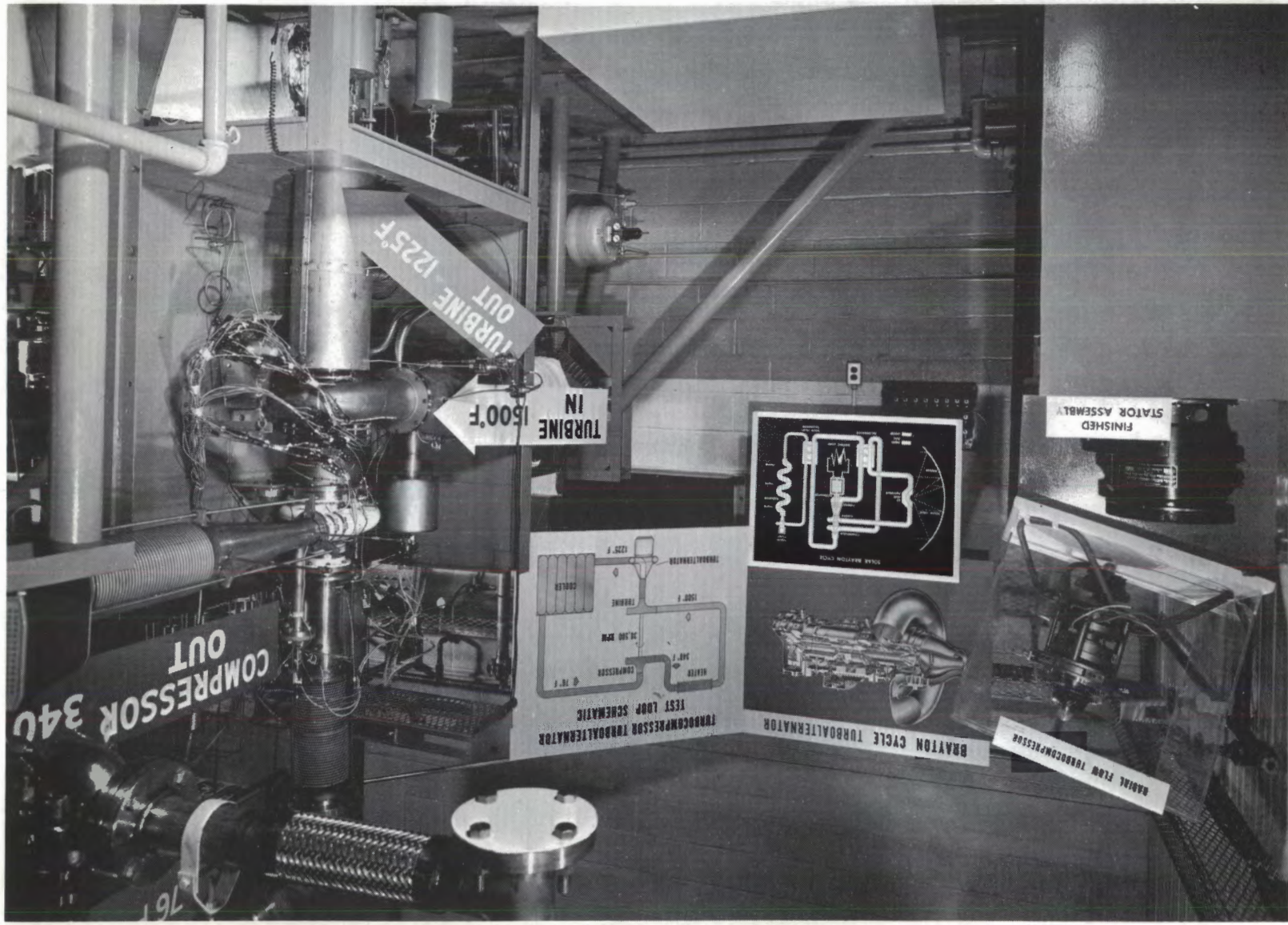
SPACE POWER - ROTATING SYSTEMS

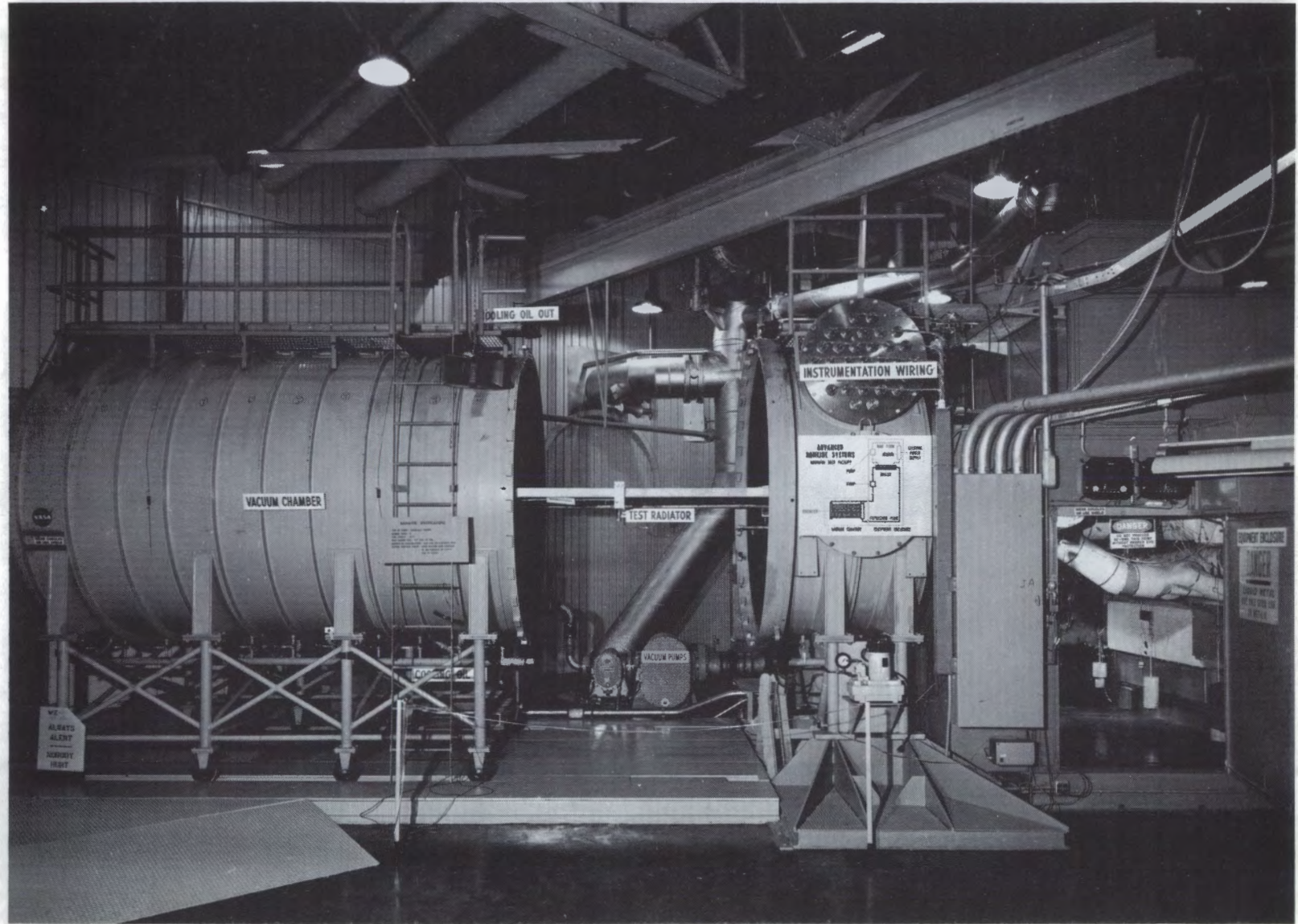
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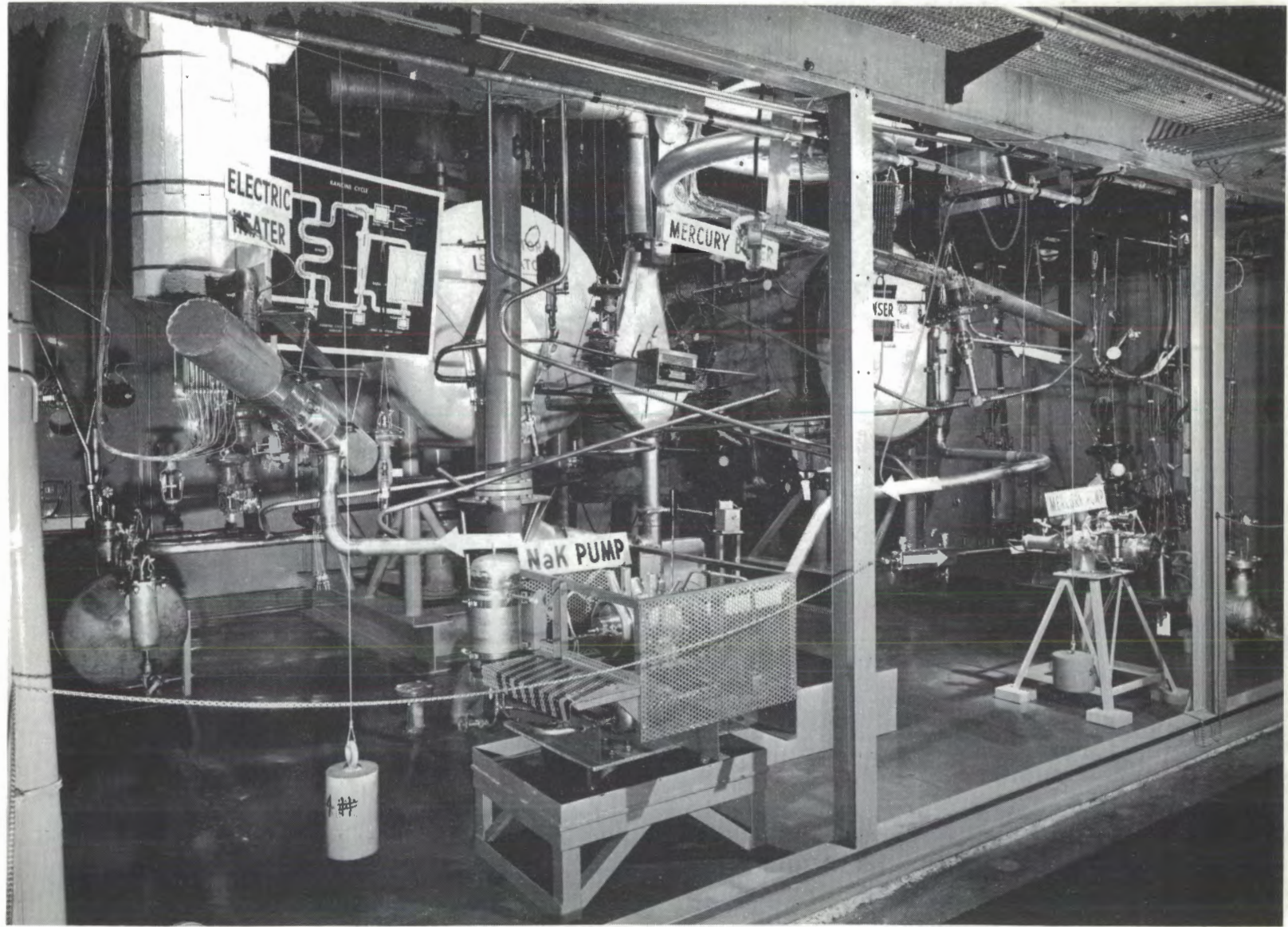
1966 Inspection of the
Lewis Research Center
Cleveland, Ohio
October 4-7, 1966

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION









SPACE POWER - ROTATING SYSTEMS

INTRODUCTION

Welcome to the space power rotating systems presentation. At this stop we will discuss rotating or turbogenerator systems as a means of generating electric power in space. In our homes, we have electric power at our finger tips, from flipping on a light switch to turning on our TV sets. We rely upon municipal power and light companies which normally burn coal, generating steam, which drives large turbogenerators, producing millions of kilowatts of power. In space, we need electric power, but we do not need millions of kilowatts. A manned-orbiting space station (fig. 1) could require 10 to 20 kilowatts for time durations of 1 to 5 years. A permanent lunar base (fig. 2) could require 100 or 200 kilowatts of power for more than 1 year of operation. And, if we look into the far distant future, an interplanetary vehicle (fig. 3) which used electric propulsion rockets could require 1000 or more kilowatts of power.

At this presentation we will describe what we are doing at this Center to advance turbogenerator system technology so that these future mission power requirements can be met with compact, lightweight systems. You will tour three test facilities where turbogenerator system components are being tested.

We have under consideration two types of turbogenerator systems - the Rankine cycle system and the Brayton cycle system. The Brayton cycle system is a close-cycle gas turbine engine. It is applicable in providing power from about 2 to 100 kilowatts. Either solar or nuclear energy can be utilized. If we use solar energy, a large mirror is used to collect and concentrate enough sunlight to heat an energy absorber. If this system were orbiting the Earth, it would pass through the Earth's shadow once per orbit. The energy absorber must be designed to store sufficient heat energy so that the system can operate during the period when sunlight is absent. The energy absorber heats

a system operating gas such as argon up to 1500° F. This hot gas is expanded through a turbine which drives a compressor circulating gas around the system. The hot gas then expands through a second turbine driving an alternator to produce the electric power. These two units we call the turbocompressor unit and the turboalternator unit. Part of the unused heat is returned to the system; the remaining heat is waste heat which is exchanged to a liquid filled loop where it is rejected to space from a radiator.

On the stage are a few Brayton-system components. This is an actual full-size turbine wheel, here is a compressor wheel, and over here is an experimental compressor unit. During your test facility tour, these units will be described in further detail, and you will see where the turbocompressor and turboalternator units are tested. This is a one-quarter scale model of a conceptual 8-kilowatt Brayton system. In the background you see the large mirror, in the center the power conversion unit, and around the outside, the radiator for rejecting waste energy.

The second type of turbogenerator system is the Rankine cycle system. Most municipal power and light companies use the Rankine cycle for steam that is used to drive turbogenerators. In applying the Rankine cycle for use in space, we are forced to go to higher operating temperatures like 1300° to 2200° F. At these temperatures, instead of using steam we use liquid metals such as mercury or potassium. The Rankine cycle systems are higher power systems than the Brayton. They are applicable in providing power from about 20 kilowatts to 1000 or more kilowatts. A nuclear reactor is used to heat a liquid metal, which transfers energy to a boiler where mercury or potassium is vaporized. This vapor is expanded through a turbine, driving an alternator, which generates the electric power. The vapor is liquefied, then circulated back to the boiler. To liquefy the vapor, a liquid metal circulates through the condenser, removing waste energy, which is then rejected to space from a radiator. A Rankine

cycle system which NASA has under development is the SNAP-8 electrical generating system. It is designed to provide 35 kilowatts of power for a little over 1 year of operation. The maximum cycle temperature is 1300⁰ F, and the working fluid used is mercury.

We have on the stage a few of the SNAP-8 components. This is a full-scale model of the SNAP-8 reactor which is being developed by the Atomic Energy Commission. The energy output of this reactor is equivalent to the combustion of about 2 million pounds of coal. Here is a SNAP-8 mercury pump used at this point in the system to circulate mercury, and the SNAP-8 alternator which is used to generate the electric power. You will see most of the SNAP-8 components and where these components are tested together as a system during your test facility tour. We are also advancing technology towards a higher power Rankine system, one that could provide 1000 or more kilowatts of power. In order to minimize the size of the radiator, we are forced to go to higher cycle temperatures like up to 2200⁰ F. At these temperatures, instead of using mercury we use a liquid metal such as potassium. We have here a two-stage turbine wheel which is designed to operate on potassium vapor. A unit almost identical to this recently completed 5000 hours of test time at a potassium vapor inlet temperature of 1500⁰ F. We are also conducting boiling and condensing experiments using potassium and sodium. During your test facility tour, you will see where these experiments are conducted.

BRAYTON CYCLE TEST FACILITY

This facility is being used to test the Brayton cycle turbocompressor and turboalternator. The facility is capable of operating at exact Brayton cycle temperatures, pressures, and power levels. Argon gas is currently being used in the facility, but mixtures of other inert gases will be used in the future. To aid in your understanding of this loop, its operation, and the arrangement of the

equipment, we have prepared this test loop schematic. The principal pieces of equipment in this rig are an electrical heater, which is located to your far right in a horizontal run of pipe; the facility cooler, which is that large piece of equipment behind you; the Brayton cycle turbocompressor, which is installed here; and the Brayton cycle turboalternator, which has not as yet been installed in the loop - but will be installed here.

During operation, the compressor provides pressurized argon gas to the electric heater. The heater raises the temperature of this gas to 1500° F and the gas then flows to the turbine. The hot gas drives the turbine, and the exhaust from the turbine then passes to the facility cooler. The temperature of the argon gas is reduced to 76° F in the cooler, and the gas flows back to the compressor, closing the cycle. The gas is then recycled through the loop.

Currently, this facility is being used to test the Brayton cycle turbocompressor. This is the turbocompressor with the housing removed so that you can see some of the internal parts. These parts are the 6-inch-diameter compressor rotor, a 6-inch-diameter turbine rotor, and a common shaft which is designed to rotate at 38 500 rpm. The shaft is mounted on gas-lubricated bearings. These bearings run on a thin film of argon gas, thinner than the thickness of a human hair. The fact that argon gas is used in the loop and also as the lubricant for the bearings eliminates the need for a separate oil lubrication system and eliminates any contamination problems which would be associated with a separate oil-lubrication system.

To date, this turbocompressor has been operated satisfactorily to a turbine-inlet temperature of 1200° F. Future tests will see this temperature raised to 1500° F.

Upon completion of the turbocompressor tests, a Brayton cycle turboalternator will be added to the loop. This is a cross-sectional drawing of the turboalternator showing the principal parts. They are a turbine assembly, an alternator assembly, and, again, the gas-

lubricated bearings. These two machines, incidently, are the first to run on gas-lubricated bearings in the space power system.

The turboalternator is designed to deliver 8000 watts or, 8 kilowatts, of usable electric power in space. The component parts of the turboalternator, the alternator, that you see here, and the turbine, are being tested separately at another Lewis facility. The objectives of this facility are to verify the design performance of the turbocompressor and the turboalternator both during startup and during long-term endurance tests. Particular attention will be paid to the performance of the gas-lubricated bearings. The results of these tests will then be used to help to predict the performance of the complete solar Brayton space power system more accurately.

ADVANCED RANKINE TEST FACILITY

In this liquid-metal facility, we study the condensing radiator for use in the advanced Rankine cycle space power system. To test such a radiator as this on the ground, it is necessary to simulate conditions of space, namely, the low pressure and the low temperature. We do this here by placing the test radiator in this vacuum chamber which has oil-cooled walls to dissipate the heat given off by the radiator. In operation, potassium vapor at temperatures as high as 1400° F enters the radiator at this end, and as it flows down the tubes, gives up heat which is radiated to the oil-cooled chamber walls. As the vapor loses heat, it condenses back to the liquid state and the liquid is collected at this end of the radiator where it is further cooled before being pumped back to the boiler. The boiler is located at the far end of this large enclosure on your right. This radiator has operated continuously for over 300 hours, at temperatures as high as 1400° F. During operation, we photographed it through a viewport on the far end of the vacuum chamber. On the screen behind you I have a photograph we have taken (fig. 4). The bright yellow pipe

at the top is the inlet manifold where the vapor is distributed to the nine tubes. The orange area covering most of the tubes is where the vapor is condensing and the dark red area at the bottom is where the liquid condensate is being further cooled before it is pumped back to the boiler. You will notice that the condensing lengths, that is, the orange area of the tubes, are all nearly the same. Because of this we have concluded this radiator design and operation was successful.

As you leave this facility, you will visit a companion one where we study the boiling of the alkali metals - at present sodium. The boiler presently under test has been operated for over 900 hours and is a single tube and shell configuration. Liquid sodium enters this tube and is boiled at temperatures as high as 2000^o F. The heat source for this boiling is another stream of liquid sodium at temperatures as high as 2200^o F flowing in the annulus around the tube. Because of these high temperatures and pressures involved, the test boiler and several other pieces of research equipment were fabricated from a refractory metal, columbium - 1 percent zirconium. To protect the columbium from serious oxidation at these high temperatures, we operated the columbium components under very deep vacuum. As you walk through the facility, some of the major components you will be able to see are the electric power supply used to heat the sodium initially, the vacuum equipment, the vacuum chamber of which the door has been opened so that you can see some of the columbium components inside. And, as you leave the facility, there are two large enclosures that house the service equipment used to supply sodium to the test boiler.

SNAP-8 TEST FACILITY

What you see being assembled here in the SNAP-8 research facility is not a flight system. It is a test rig that incorporates all of the major flight components with the exception of the nuclear reactor

and the flight radiator. In contrast to the compact flight system, this configuration is intentionally spread out to allow for component accessibility, and to accommodate instrumentation, special control devices, and auxiliary fill, dump, and filtration systems. During system operation, this entire enclosure in which we are standing is sealed and filled with dry nitrogen gas. This is a precaution against fire hazards due to accidental spillage of highly reactive liquid metals used in this system.

In this system we have the three basic loops of the SNAP-8 system. In the primary loop, this 650-kilowatt electric heater together with an analog computer, which controls its power, approximate the behavior of the flight reactor. A flight prototype pump circulates the liquid-metal fluid, which transfers energy from the heater to this flight design boiler. In the secondary loop, mercury vapor leaving the boiler at a temperature of 1275⁰ F and a pressure of 275 pounds per square inch drives this turboalternator assembly, producing 35 kilowatts of usable electricity. Turbine exhaust is liquefied in the condenser, again a flight component, and is returned to the boiler by this mercury pump. A third liquid-metal loop transfers the waste heat from the condenser to the simulated radiator components located in the two tanks at the rear of the cell.

During the past year, a workhorse system was operated in this facility. At that time we studied basic control requirements, solved problems associated with system operation, and developed the reactor and radiator simulators used in the present system. Test objectives for this system include dynamic and control studies, evaluation of system performance, and realistic startup investigations. The equipment associated with data acquisition and system control, as well as the analog computer used in the reactor and radiator simulators, is located in the remote control room.

In the static display area you will have a chance to examine a one-quarter scale model of a proposed flight configuration.

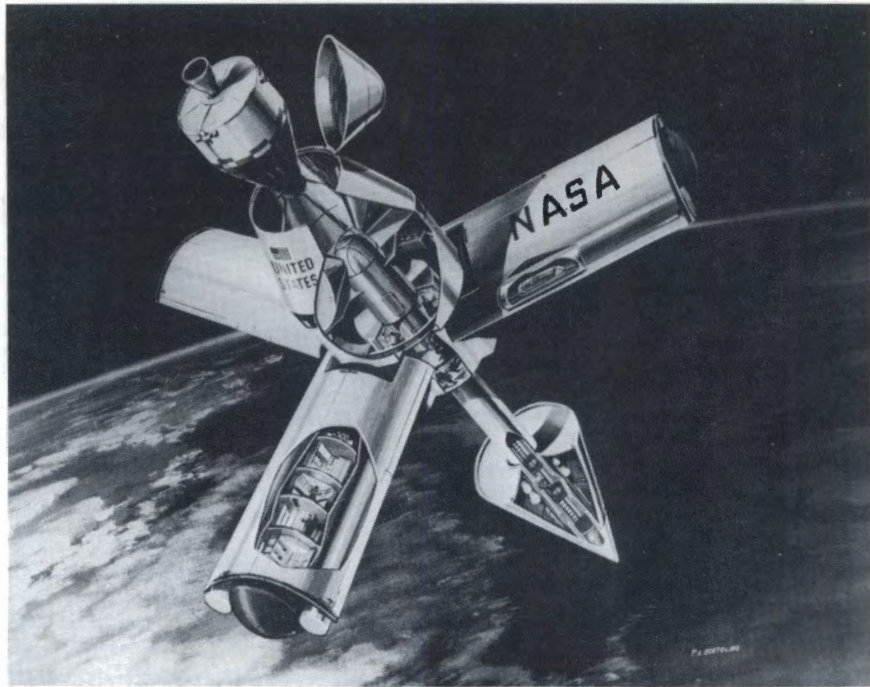


Figure 1

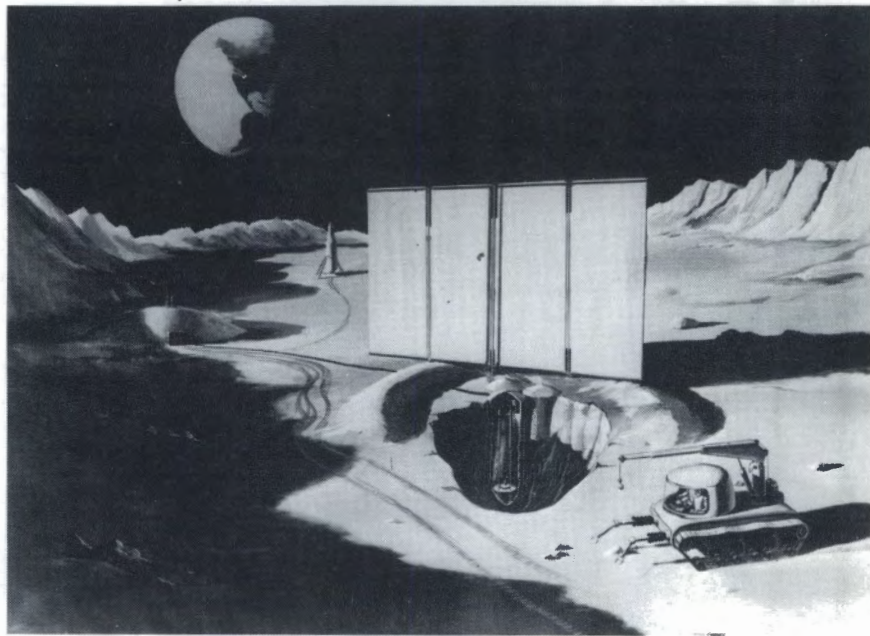


Figure 2

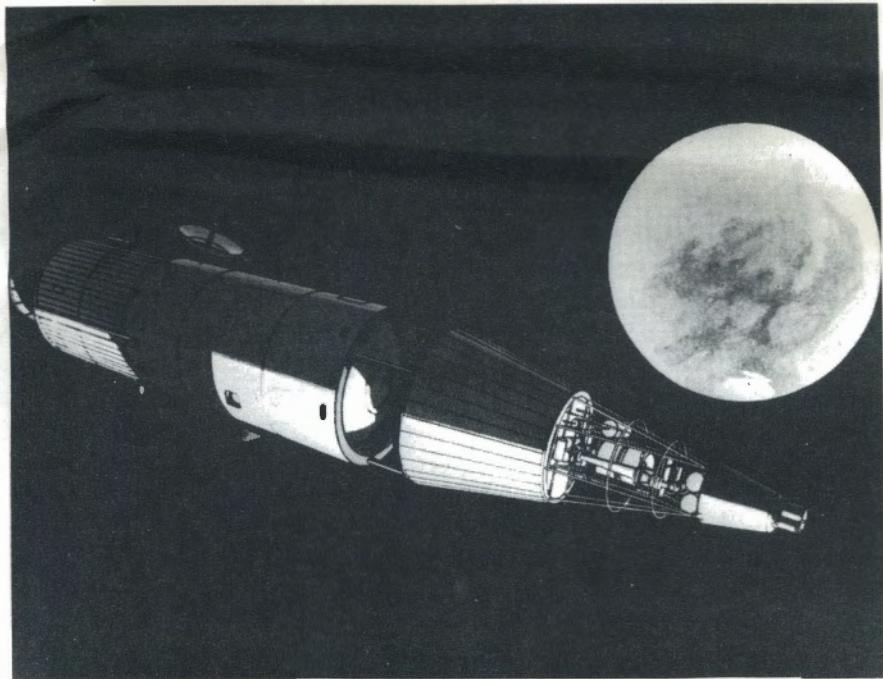


Figure 3

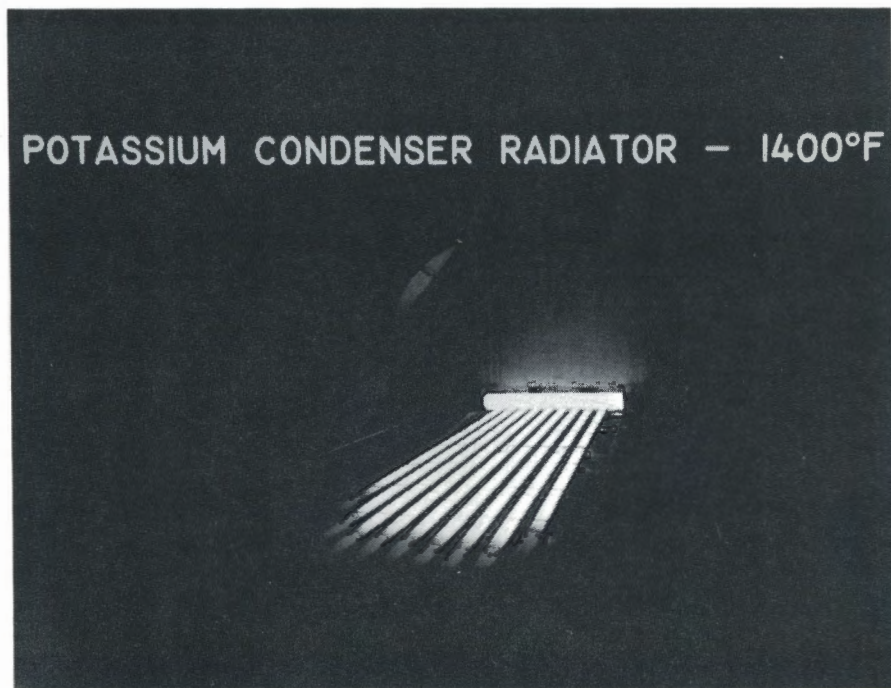


Figure 4

NASA
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SNAP-8 MERCURY CORROSION LOOP

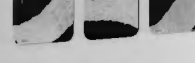
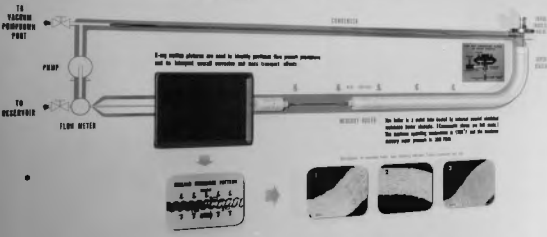
MATERIALS COMPATIBILITY INVESTIGATION



SNAP-8 MERCURY CORROSION LOOP (MCL) MATERIALS COMPATIBILITY INVESTIGATION (MCI) FOR CONTEMPORARY SPACEFLIGHT, UNMANNED SPACE FLIGHT, AND SPACE STATION. THIS LOOP SIMULATES CONDITIONS PRESENT IN A MERCURY LOOP TO IDENTIFY TYPES, LOCATIONS AND EXTENTS OF CORROSION AND TO MAKE TRANSPORT EFFECTS.

CONSTRUCTION

Long temperature ranges (up to 2000°F) and various materials involved with liquid mercury are subject to stress. In the investigation of parts of the loop, material is broken up to simulate 2-1/2 mg. fragments.



TUBE-IN-TUBE BOILER (MCL-2) PW BOWMAN

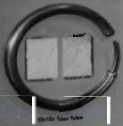
SNAP 8



SNAP-8 MERCURY CORROSION LOOP

POTASSIUM RANKINE SYSTEM

PROTOTYPE
CORROSION LOOP



Component	Material	Temperature (°F)	Pressure (PSI)	Corrosion Rate (mm/yr)
1	Aluminum	500	100	0.05
2	Aluminum	500	100	0.05
3	Aluminum	500	100	0.05
4	Aluminum	500	100	0.05
5	Aluminum	500	100	0.05
6	Aluminum	500	100	0.05
7	Aluminum	500	100	0.05
8	Aluminum	500	100	0.05
9	Aluminum	500	100	0.05
10	Aluminum	500	100	0.05
11	Aluminum	500	100	0.05
12	Aluminum	500	100	0.05
13	Aluminum	500	100	0.05
14	Aluminum	500	100	0.05
15	Aluminum	500	100	0.05
16	Aluminum	500	100	0.05
17	Aluminum	500	100	0.05
18	Aluminum	500	100	0.05
19	Aluminum	500	100	0.05
20	Aluminum	500	100	0.05

PROTOTYPE
CORROSION LOOP



300 KW FACILITY



100 KW FACILITY

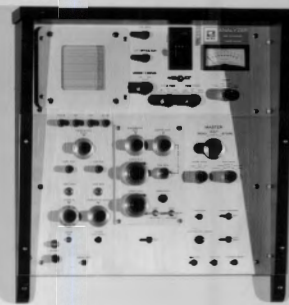


SEMICONDUCTOR RADIATION DETECTOR



PHOTO MULTIPLIER
SCINTILLATION DETECTOR

RADIOACTIVE
SOURCE

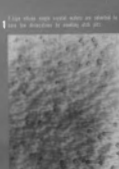


Nuclear radiation detectors designed and fabricated at the Lewis Research Center are simpler, have better resolution than conventional scintillation detectors, and are becoming widely used in both space and laboratory experiments. This demonstration shows counting of the same radioactive source by both types of detectors.

The detector in operation has an illuminated panel. After 10 seconds of accumulation, the energy analyzer will display the energy spectrum of the radioactive source. Note that the semiconductor spectrum has narrow lines. This indicates good energy resolution.

FABRICATION

. . . The step-by-step sequence, together with the device at the corresponding stages, is shown below. The Lewis effort has achieved thicker detectors than are commercially available.



1. Thin silicon wafer (100 ohm-cm) is mounted in the detector housing.

2. The wafer is etched to form a shallow groove.

3. The wafer is coated with a thin layer of silicon dioxide.

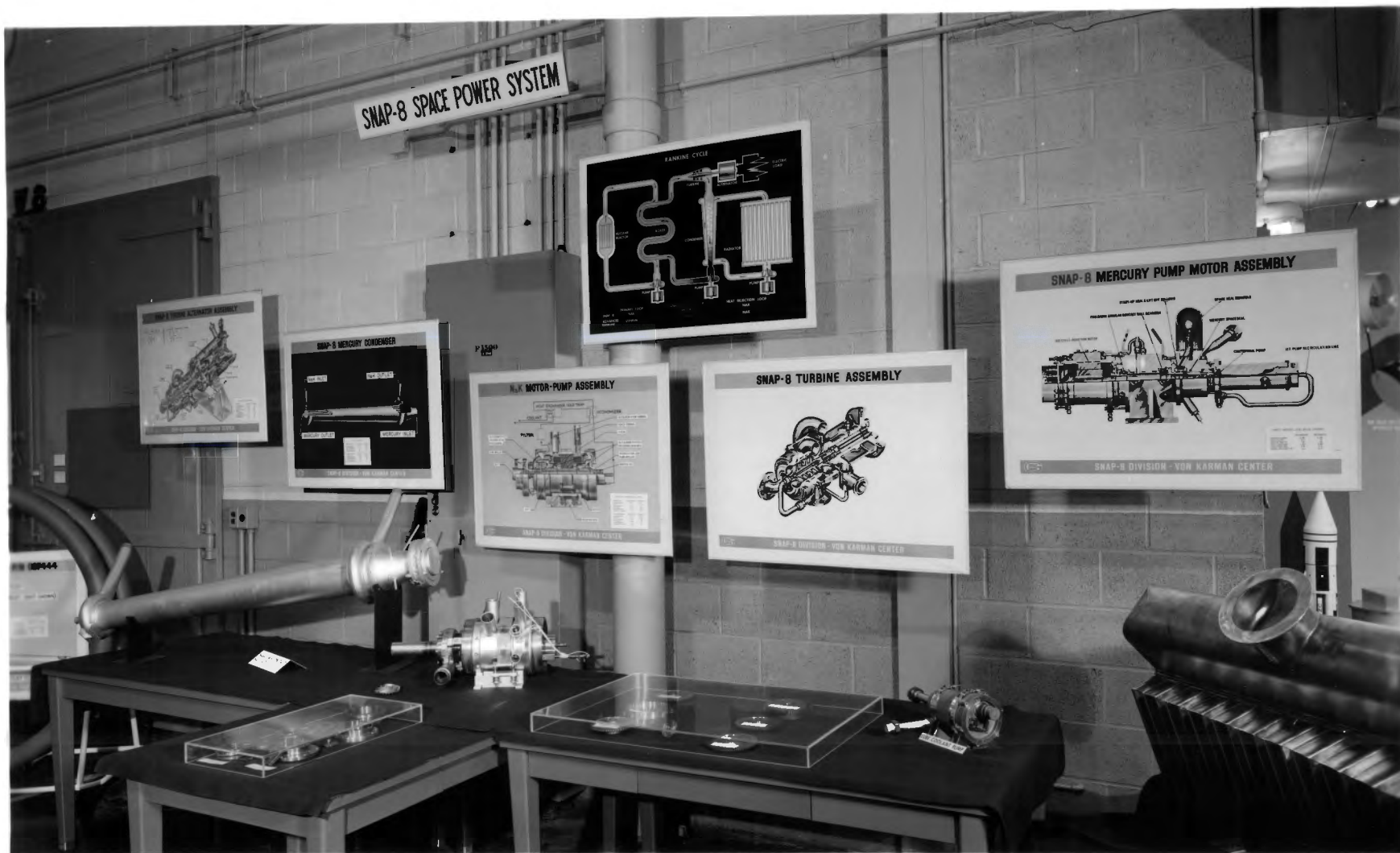
4. The wafer is etched to form a shallow groove.

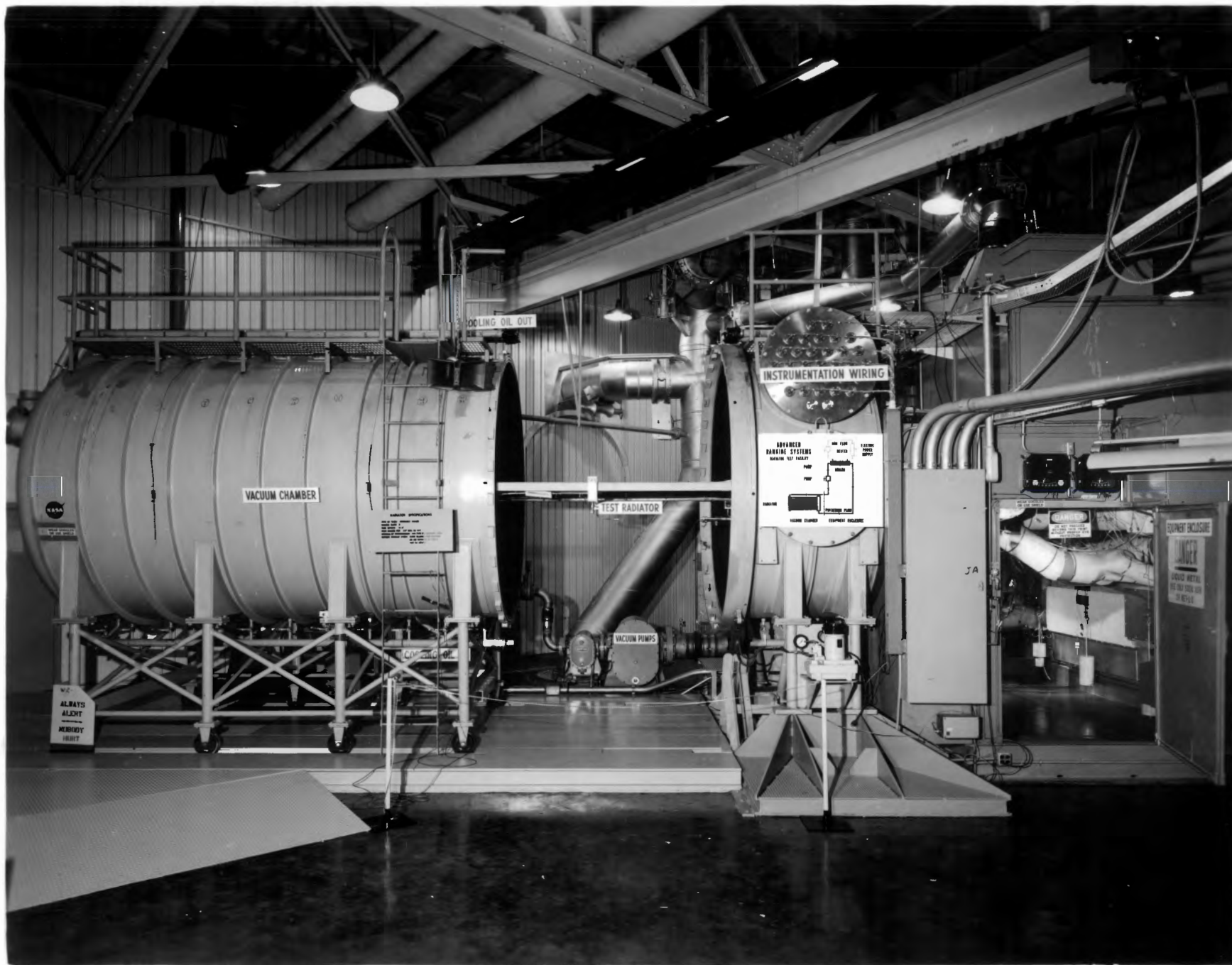
5. The wafer is etched to form a shallow groove.

6. The wafer is etched to form a shallow groove.

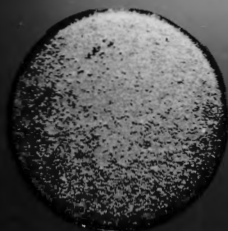
7. The wafer is etched to form a shallow groove.

8. The wafer is etched to form a shallow groove.

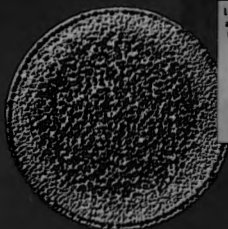




CAVITATION DAMAGE TO METALS



L-605 Cobalt base alloy after exposure
 in sodium for 4 hours at 800° F

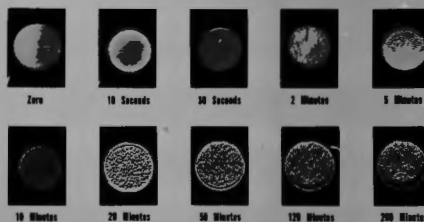


L-605 Cobalt base alloy after exposure to cavitation
 in mercury for 4 hours at 300° F

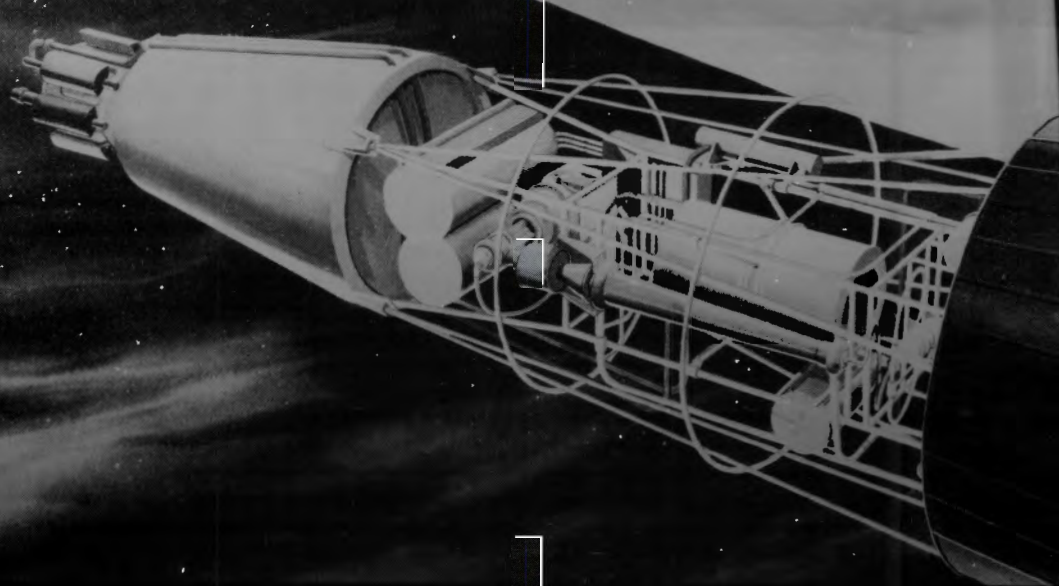
L-605 Specimens before
 and after exposure to
 cavitation in mercury



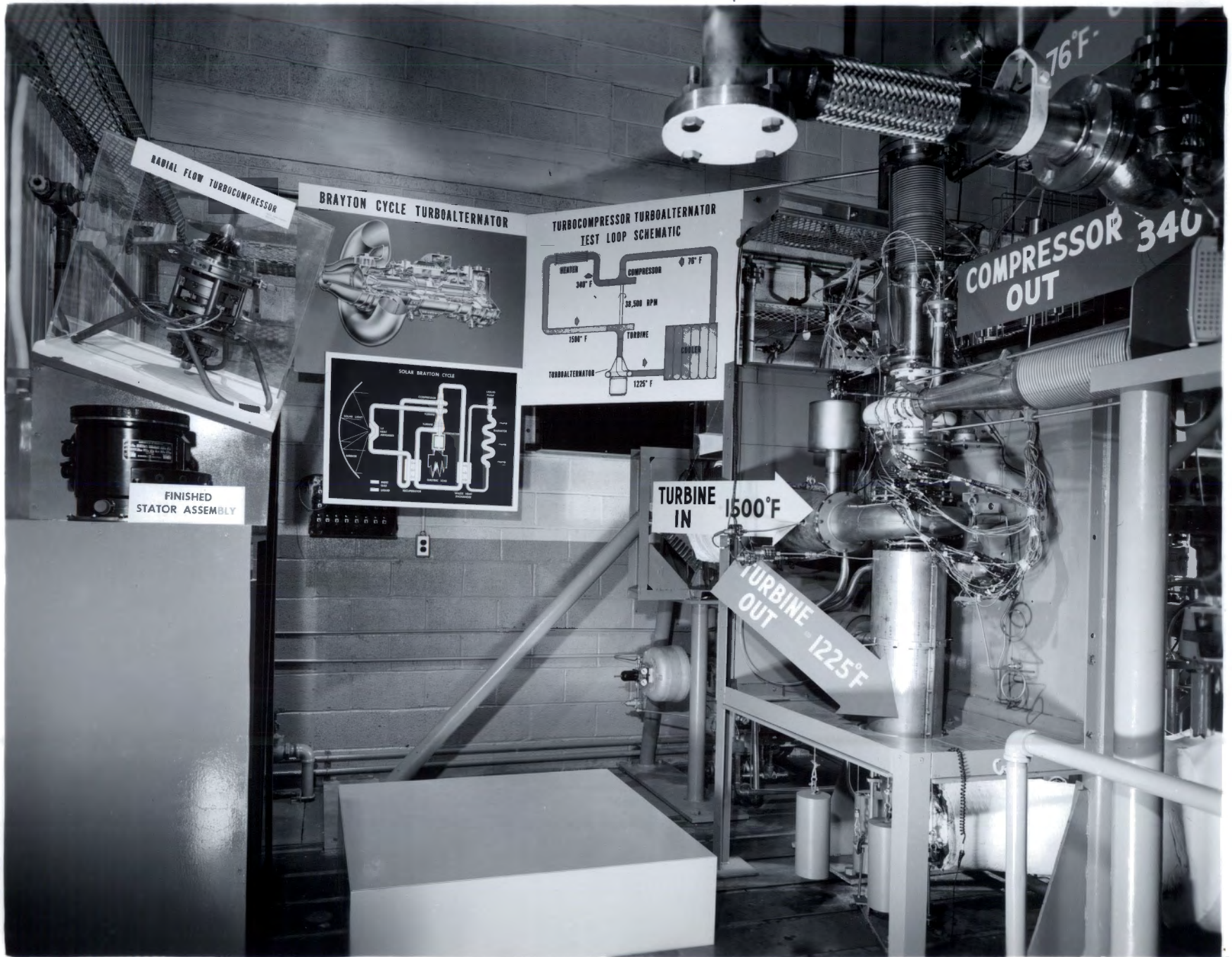
CAVITATION, the formation of bubbles or cavities in liquids under extreme pressure fluctuations, causes damage to metals in contact with bubbles that collapse. Since liquid metals are essential components in space power systems, the relative cavitation damage to high strength steels, cobalt- and nickel- base alloys, and refractory metal alloys in a high temperature liquid metal environment is being studied.



Damage to aluminum after exposure to cavitation in water
 for various time intervals at room temperature.

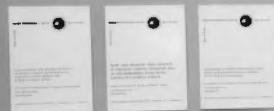
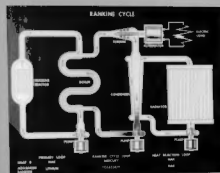






NON - CONTACT SHAFT SEALS

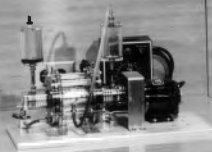
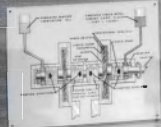
SPACE POWER SYSTEMS WHICH MUST OPERATE UNATTENDED FOR YEARS, BEARING SHAFT SEALS WITH EXTREMELY LOW LEAKAGE RATES. THESE SEALS ARE UNDER STUDY AT LEONIA RESEARCH CENTER. MIN. LEAKAGE AS LOW AS 0.0001 POUNDS PER HOUR HAS BEEN ACHIEVED AND RELIABILITY IS HIGH SINCE THERE ARE NO SOLID SURFACES IN RUBBING CONTACT.



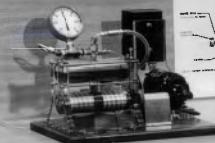
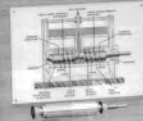
VISCO SEAL



SEAL SYSTEM



VISCO SEAL



CENTRIFUGAL SEAL

