SPACE VEHICLE TECHNOLOGY

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The subject of our presentation is "Space Vehicle Technology." Perhaps the best way to discuss this subject is to show you a typical complex advanced space vehicle concept, and use this as a focal point for explaining technical problem areas and how we go about finding solutions.

This is a 1/10-scale model of one approach to providing a manned earth-orbital research laboratory. Such a laboratory offers a flexible research tool for conducting extensive experimentation in a weightless environment for long periods of time. The basic laboratory would be launched by a Saturn booster and placed in a near earth orbit. The laboratory is designed for a lifetime of from 1 to 5 years and could accommodate 6 crewmen. Because of its long lifetime, supplies must be delivered to the laboratory at defined intervals, and it becomes necessary to periodically replace crew members with fresh personnel. This resupply and crew rotation could be accomplished by making use of existing spacecraft such as Apollo or a Gemini vehicle shown here in the docked position.

Of course other spacecraft concepts are being studied. Typical examples are toroidal vehicles represented by the model overhead and winged, maneuverable configurations represented by this model. Obviously, the NASA's research programs are comprehensive, and much of the technology developed for one configuration is applicable to other configurations as well. The technology for concepts such as these is being developed jointly by in-house efforts within the NASA and by contract efforts with industry.

One of the problems associated with a space vehicle concerns selection of its orbit altitude, and this selection depends to a large degree on knowing the variation of air density with altitude. Even the extremely small amount of air remaining hundreds of miles above the earth's surface results in drag forces which eventually cause the vehicle to spiral back into the dense portions of the atmosphere.

The experimental satellites designed to measure the density of the upper atmosphere were the Explorer IX and XIX. This picture shows an artist's concept of the Air Density Satellite in orbit. The inflated satellites were 12 feet in diameter and weighed 17 pounds. The polka dots were used to control the temperature of the surface. The satellites were fabricated from layers of aluminum and plastic film with a combined thickness of two-thousandths of an inch. During launch, the satellites were folded in this type of canister. After reaching orbit altitude, the satellites were ejected from the container and inflated by nitrogen gas. A full-sized Explorer is on display in the hangar.

The atmospheric density at a given altitude is related to the satellite's orbit decay. Therefore, by accurately measuring the orbit decay of the Explorers with optical tracking stations located at various points on the earth, the high-altitude density was defined. This graph illustrates the application of the Explorer IX and XIX data. It shows the altitude at which the MORL must be placed to achieve a desired lifetime in orbit. For example,

if the MORL were placed in a 200-nautical-mile orbit, the mission duration would be limited to approximately 100 days. Thus to achieve our prescribed minimum 1-year orbit lifetime (point to 365-day region), we must increase the orbit altitude or add in-orbit propulsion.

While discussing the environment as related to selection of orbit altitude we must consider the problems associated with particle radiation. The spatial distribution of such radiation is represented by this schematic. Shown are the trapped high energy protons and electrons of the Van Allen Belts, the ionizing radiation of nondirectional galactic cosmic rays, and the energetic particles which are emitted from the sun during solar flares. The distribution suggests that earth orbiting vehicles should remain in orbit altitudes below the trapped particle belts and at orbit inclinations which avoid the belt anomalies where they bend in towards the earth as they follow the earth's geomagnetic pattern. Remaining under the Van Allen Belts also helps to protect the vehicle from solar and cosmic radiations. Proper selection of orbit altitude and inclination can reduce the radiation hazard; however, the problem cannot be ignored for earth orbiting vehicles, and it is a more serious problem for vehicles which pass through the trapped particle belts and into deep space. Radiation effects can cause serious damage to spacecraft structures and materials. Here is an example of radiation damage to fused quartz crystals. This material was proposed for use as a cover for solar cells because it had good transmission characteristics. However, when exposed to high energy electron radiation, the light transmission qualities were changed to the extent that the material could not be used.

In order to further study the effects of high energy particles on space vehicles, the NASA is building the Space Radiation Effects Laboratory illustrated by this artist's concept. The Laboratory will house a synchrocyclotron capable of emitting protons with energies of 600 million electron volts. The Laboratory will be used to conduct research in basic physics, health physics, dosimetry, shielding investigations, sensor development, and materials studies.

Another problem associated with the MORL spacecraft concerns the maintenance of a relatively even "shirtsleeve" temperature inside the vehicle as it alternately traverses the sunlit and shaded portions of its orbit around the earth. The vehicle receives thermal energy directly from the sun (q sun), from sunlight reflected by the earth (q albedo), directly from the earth (q earth), and from internal sources. The vehicle loses heat through direct radiation from its surface.

The problem is a complex one. However, the technology in this area has been developed to where it appears that adequate temperature control can be achieved through proper selection and location of space cabin wall materials. For example, this composite wall section which I have here can produce the temperature distribution shown on the lower chart. The outer surface of this sample consists of a special coating having a predetermined ratio of solar absorptivity to thermal emissivity. The middle layers are composed of low-conductivity foams which act as thermal insulation. The inner layer is an aluminum honeycomb for carrying the pressure and launch loads.

The graph shows the variation of inner and outer wall temperatures as the vehicle progresses from sunlight to shadow and back to sunlight as it goes around the earth. The variation in outer wall temperature is kept relatively small by the action of the external coating. Due to the insulative properties of the inner layers, the variation of temperature for the inner wall is reduced even further, and a satisfactorily constant value is attained. Sometimes, however, because of large internal heat loads, passive techniques for controlling temperature within the required narrow limits are not adequate, and mechanical systems employing radiators must also be utilized.

Before extended manned missions in space could be safely undertaken, it was necessary to better define the micrometeoroid hazard. Micrometeoroids are small particles thought to be the debris from dead comets or the remains from collisions of rock-like bodies known as astroids. The Explorer XVI shown in this picture was designed to obtain a direct measure of the number and properties of micrometeoroid particles encountered in earth orbit. The Explorer XVI had five different types of sensors; however, the primary sensors were these pressurized half cylinders made of thin beryllium-copper. When any of these cylinders were punctured by a meteoroid, the loss of pressure inside caused a signal to be transmitted to earth.

Penetration results from this satellite are shown on this graph and are compared with estimates using results of meteor observations. The number of punctures per square foot of surface per day is plotted against the equivalent thickness of aluminum, in inches. Observe that the Explorer XVI results fall between the estimates based on Whipple and Watson which are straight lines on this log-log plot. Based on an interpolation of Explorer XVI data, the MORL would receive only one small penetration of the inner wall in 1000 years. Interpolation, however, is risky at this time. As can be seen, the Explorer XVI better defines the probability of puncture of thin materials, but less information is available on the probability of puncture of the thicker materials required for MORL type missions. Positive definition of this region of the graph will allow aerospace engineers to better establish design requirements. One advanced program designed to define this region is the "Saturn-Launched Meteoroid Experiment" which is to be conducted in the near future.

Thus we see that in the design of a manned spacecraft, we first define the environmental conditions of space by use of experimental satellites and ground tests and observations. Then, using the defined environment, we proceed to design the spacecraft structure. A typical wall structure shields and protects the crew and equipment from the vacuum, radiation, temperature, and micrometeoroid environment.

Medium sized spacecraft such as the MORL easily conform to the cylindrical configuration required during the launch phase of the mission, but the large hexagonal torus space station shown overhead cannot be launched in the orbit configuration. It must, therefore, be expanded after insertion into orbit. This small model demonstrates how the hexagonal torus is packaged during launch and later mechanically deployed into the desired shape.

A fundamental difference between the three space laboratories shown here is their characteristic gravity mode. This 1/10-scale MORL model is basically a zero-gravity configuration. However, artificial gravity capability is provided with an onboard centrifuge. An artificial gravity field is produced from the centrifugal forces inherent in rotation. The 1/30-scale model on the wall differs from the zero gravity laboratory in that it provides artificial gravity for the entire station. This is achieved by separating the same basic MORL laboratory from its last stage Saturn booster with cables and rotating the system about its center of mass. The hexagonal torus configuration shown overhead achieves an artificial gravity field by spinning the entire station about the central hub.

You might wonder why we are interested in an onboard centrifuge and in concepts for providing artificial gravity. The primary reason is for the physiological conditioning of the crew during missions of long duration. Although the need for this type of conditioning has not been firmly established at this date, we must take it into account in our studies.

The presence of man, however, does impose certain unquestionable design criteria on the vehicles. First, the internal environment must constitute a habitable atmosphere. To maintain man's vital functions we must supply the cabin with oxygen for breathing and for pressurization. We must also supply an inert filler gas if two-gas systems are used. Simultaneously we most remove gases and vapors which can accumulate in concentrations that incapacitate the crew. Examples are carbon dioxide and water vapor from exhalation, water vapor from perspiration, and a multitude of contaminants that can evolve from outside and inside the vehicle cabin.

A second problem in life support technology is to provide nutritional support and the management of waste products evolving from the metabolic process. The minimum total ingested food and water requirement is approximately 6 pounds per man per day of which $3\frac{1}{3}$ pounds are returned in the form of solid and liquid wastes.

Technological questions posed include: How do we control the composition of space vehicle atmospheres? How do we supply man's material needs? How do we handle the job of removing wastes that contaminate the atmosphere?

There are two general approaches to life support systems: (1) the stored approach and (2) the regenerative approach. In the stored approach, all necessary supplies for the entire mission are onboard at launch. In the regenerative approach, the basic stored quantity of supplies onboard at launch are supplemented with supplies regenerated from waste products.

Let us examine this chart of system weight in pounds plotted against mission duration in days. For short missions, it is practical to store all supplies. For intermediate mission durations, it becomes practical to regenerate some supplies such as usable water from waste water and urine. For extended mission durations, it is practical to regenerate water and atmosphere supplies. As can be seen a regenerative system is a must for extended mission space

vehicles. We cannot store all the necessary supplies onboard at launch because they are too large and too heavy.

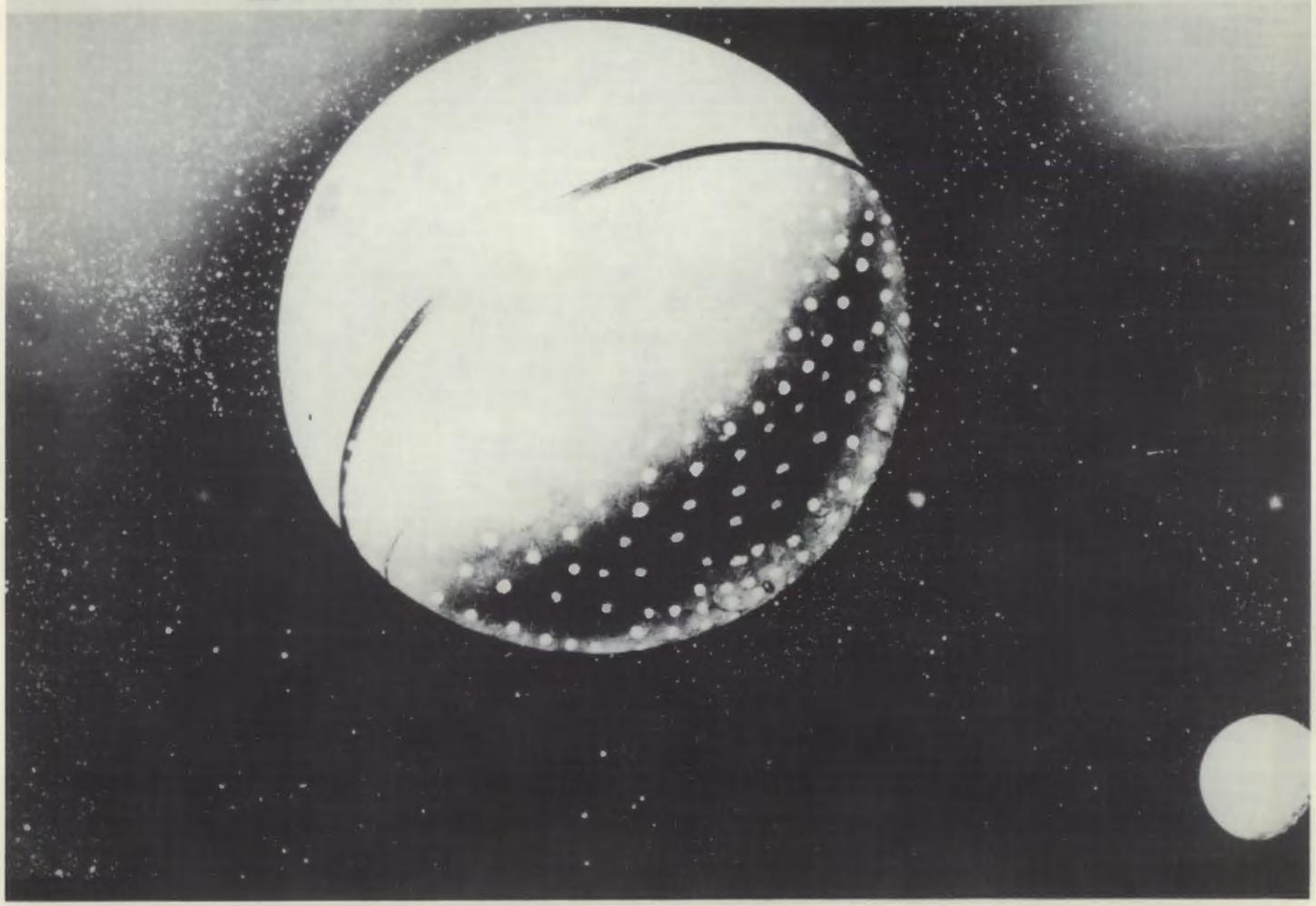
In our research on the life support problems just discussed, we are concentrating on developing the technology for regenerative life support systems for extended missions. One phase of our program is represented by these examples of life support system components. This device is a flight hardware prototype gas chromatograph utilized to detect gases present in the vehicle atmosphere. It can detect contaminants which if undetected might build up and jeopardize the lives of the crew. These three devices are components which can regenerate useful products from wastes. They are not flight type models. They are laboratory models secured in cooperation with industry and they are used to demonstrate technical feasibility of our concepts of regeneration techniques. This unit is a vacuum distillation still designed to deliver 1/2 pound of usable water per hour from waste water. This unit is a regenerable carbon dioxide sorber in which two canisters of chemical sorbers are removing water vapor and carbon dioxide from the air stream while two are being purged for the next cycle. The carbon dioxide purged from the canisters can be moved to this unit in which it is reduced electrolytically into oxygen and carbon. Thus we have recovered oxygen from the waste product carbon dioxide.

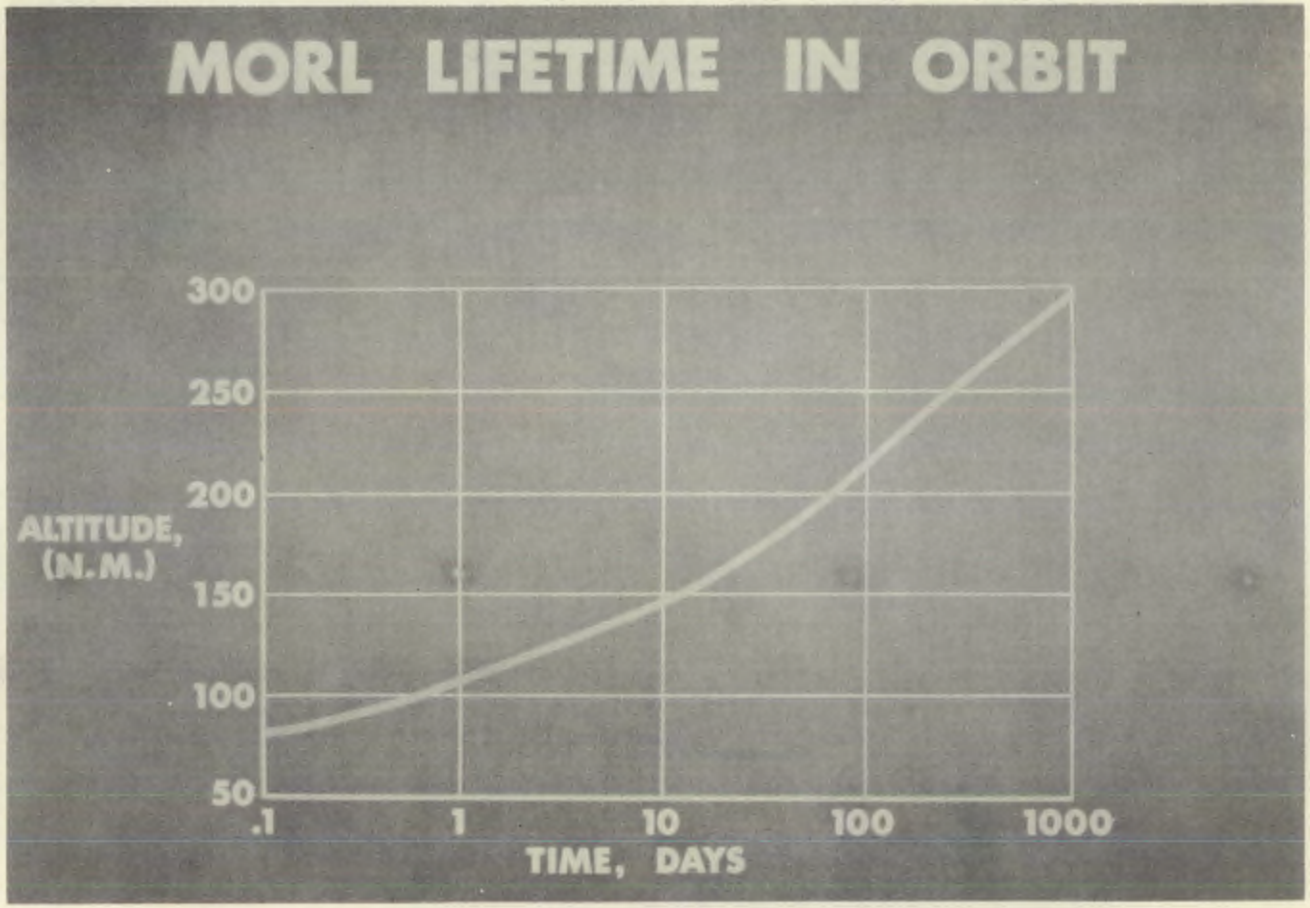
Up to this point we have been discussing individual components for life support. Another problem concerns how well these components work together, or how they can be integrated into a complete life support system. In order to study this problem we are procuring the research tool shown in this picture. It is a simulated space vehicle cabin which will contain a complete life support system for 4 men for missions lasting as long as a year. With this tool we can evaluate components, the integration of components, the relationship of the crew and the system, and also the interfaces between life support systems and other vehicle systems such as secondary power.

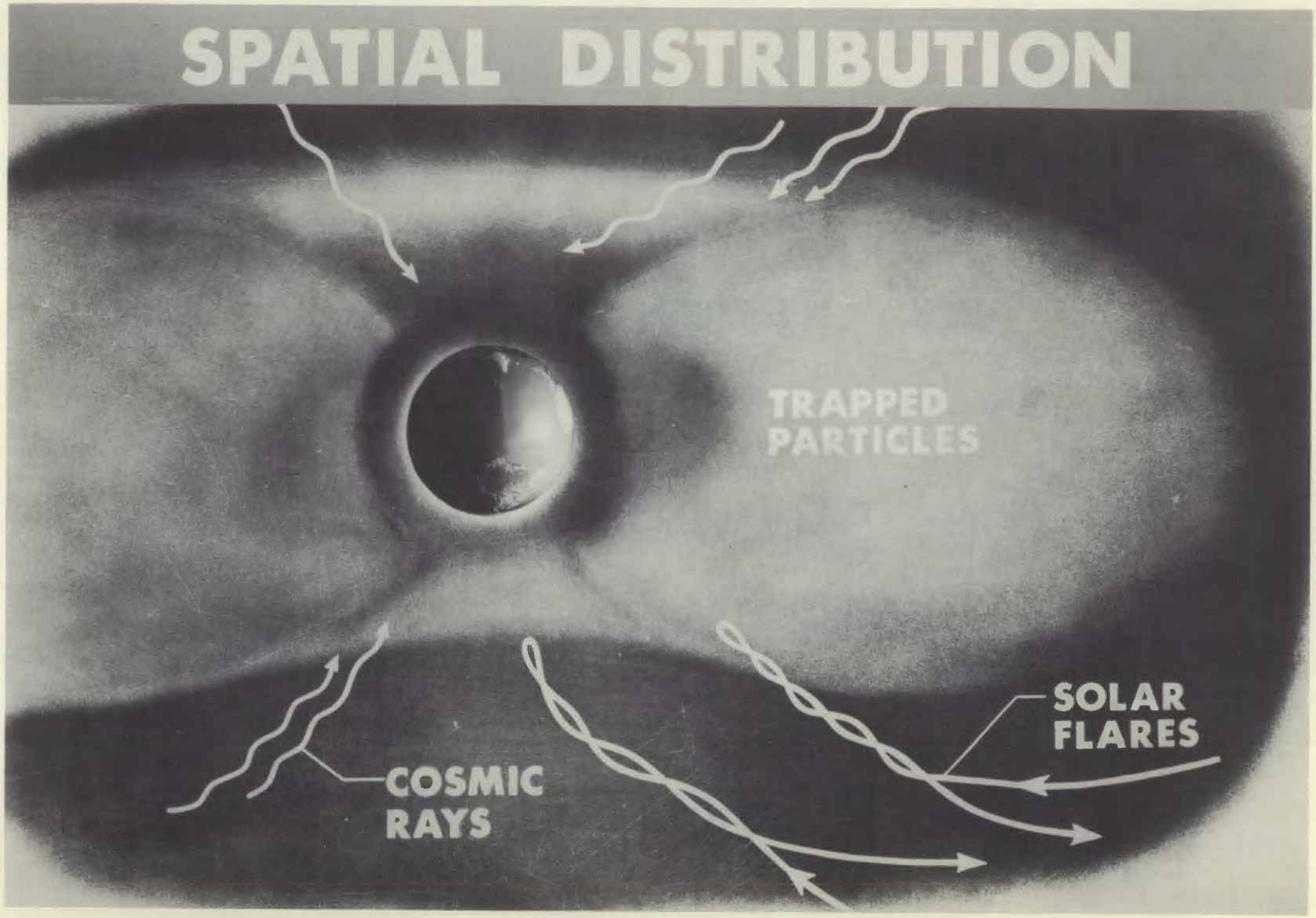
Obviously, in this one stop it has been impossible to discuss all the technologies that contribute to space vehicle development. Other problem areas, for example, in which extensive research is being conducted include power supply, communication and navigation, stability and control, and cabin-airlock leakage.

Certainly, it has become apparent to you that complex, carefully designed spacecraft systems are required for future space missions, and that the space vehicle technology being developed by NASA's Office of Advanced Research and Technology is a prerequisite to the success of these missions.

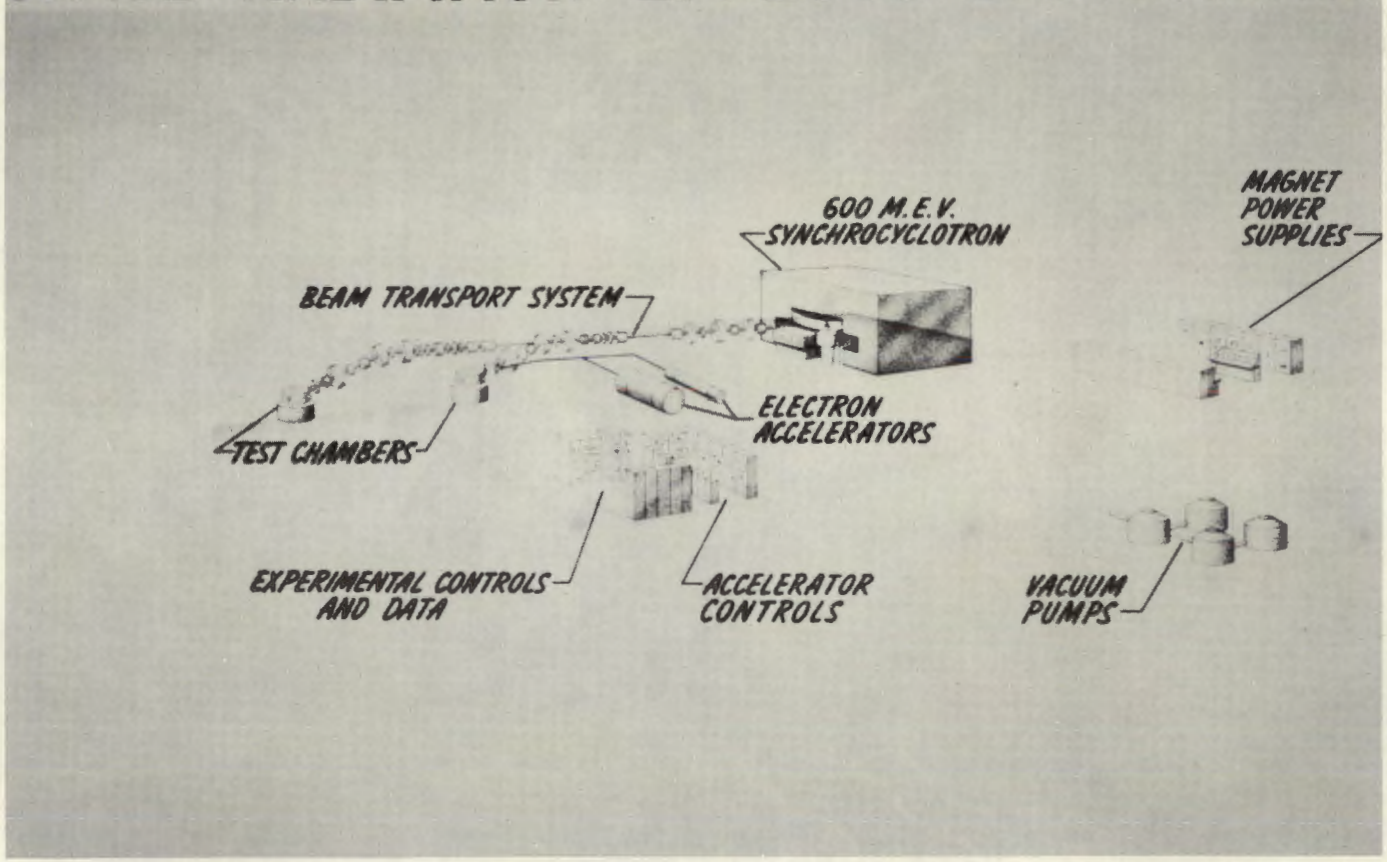
EXPLORER IX AND XIX



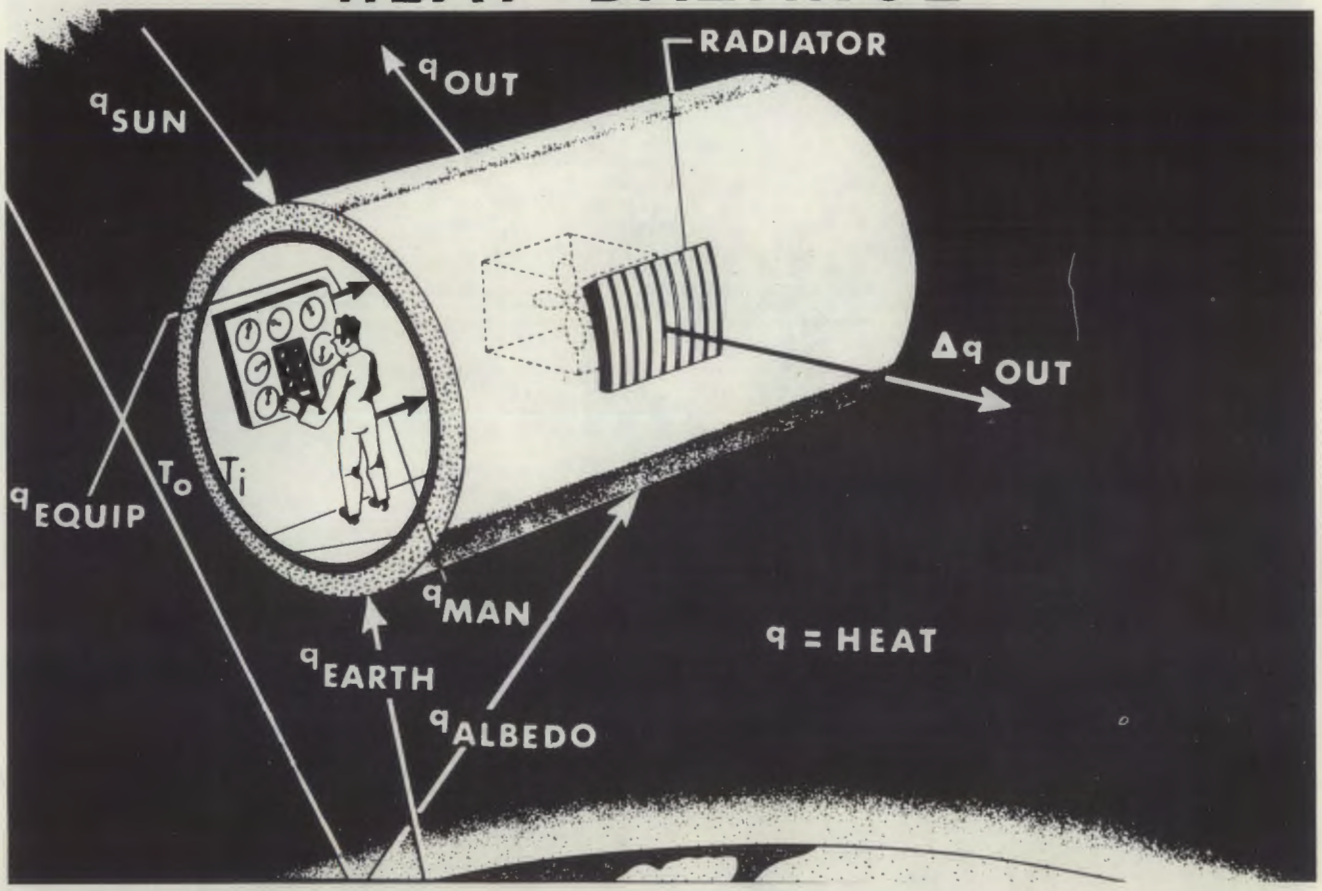

MORL LIFETIME IN ORBIT
ALTITUDE, (N.M.)
300
250
200
150
100
50
.1
1
10
100
1000
TIME, DAYS

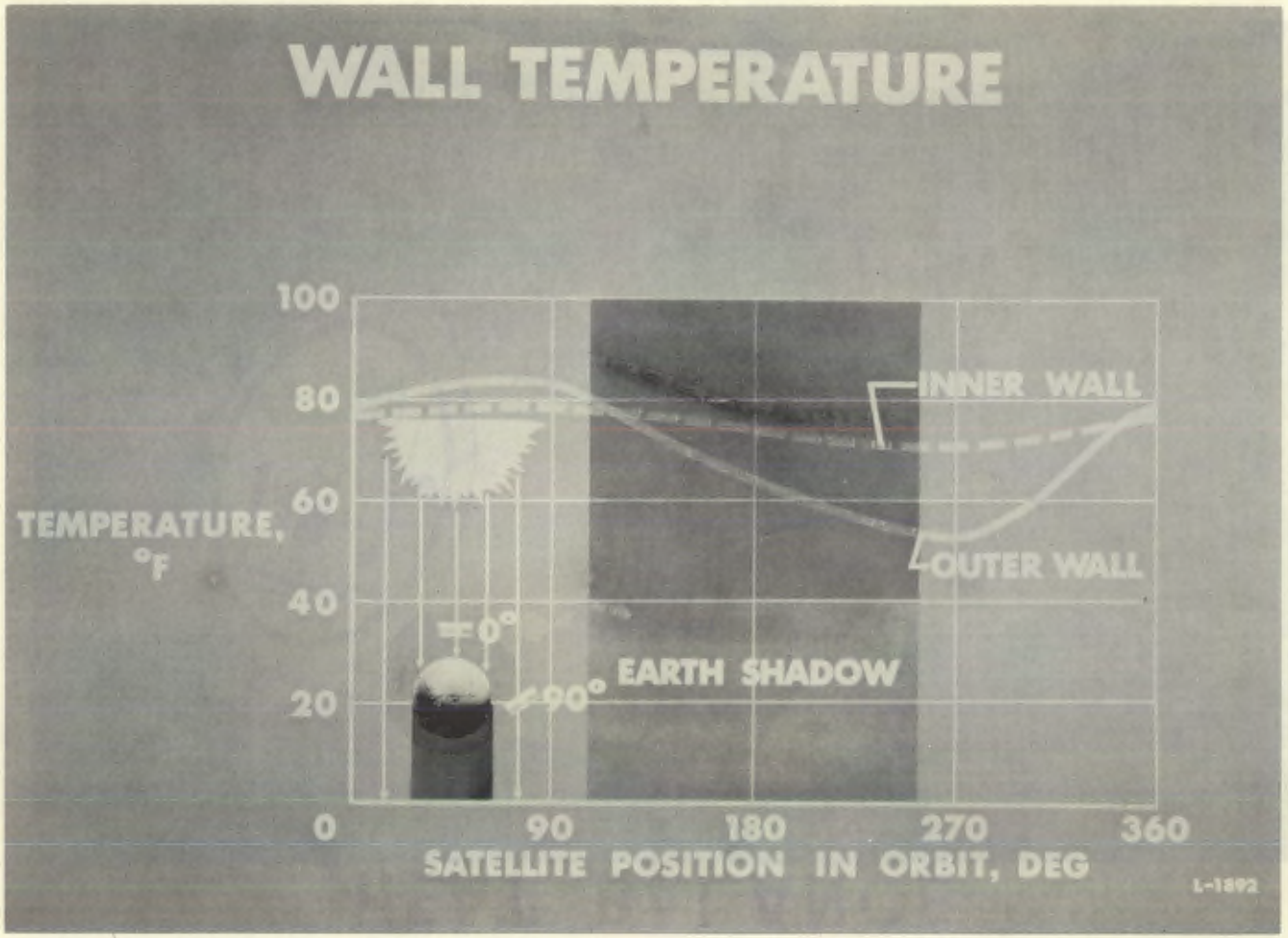

SPATIAL DISTRIBUTION
TRAPPED PARTICLES
SOLAR FLARES
COSMIC RAYS

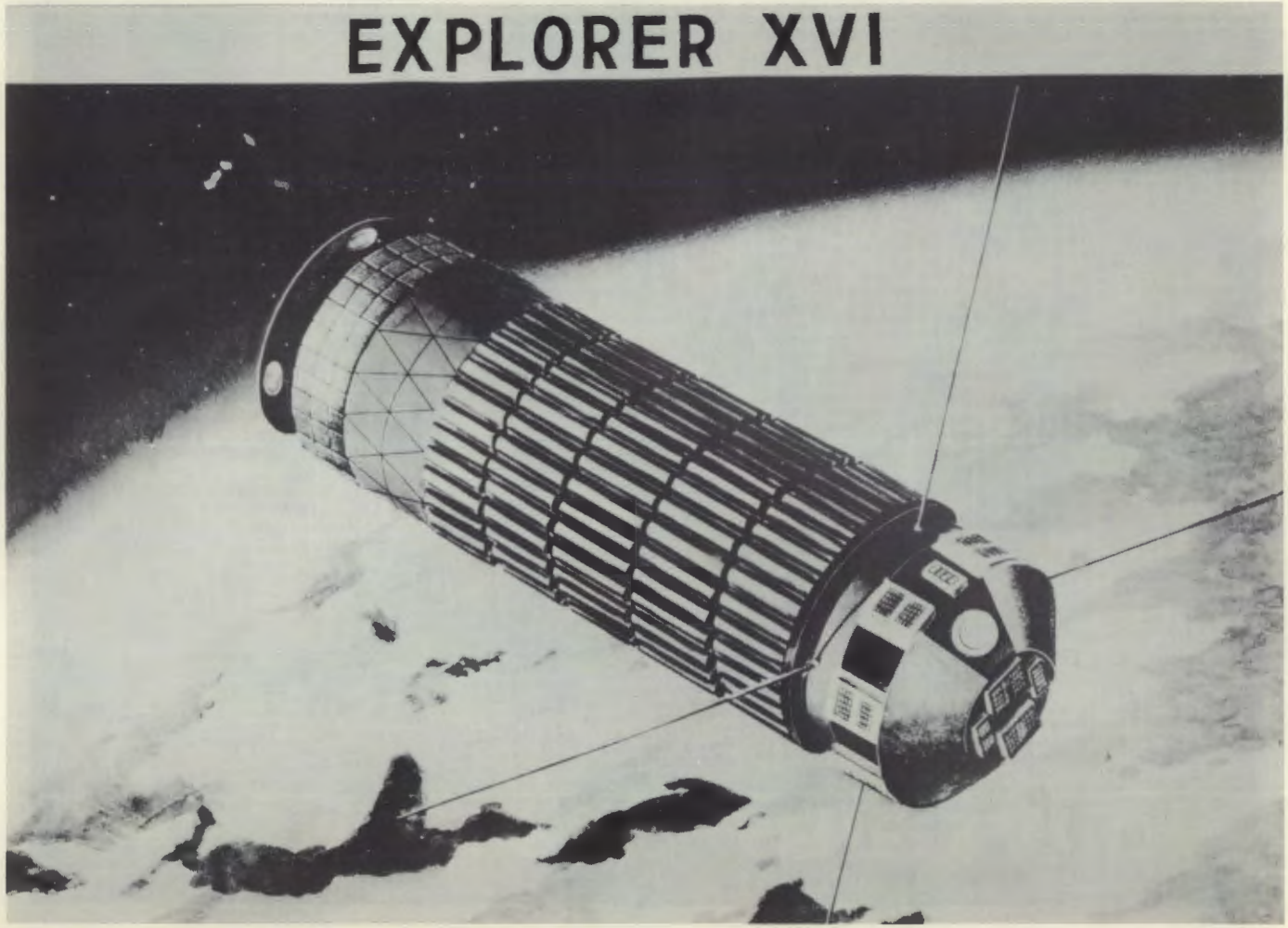
SPACE RADIATION EFFECTS LABORATORY

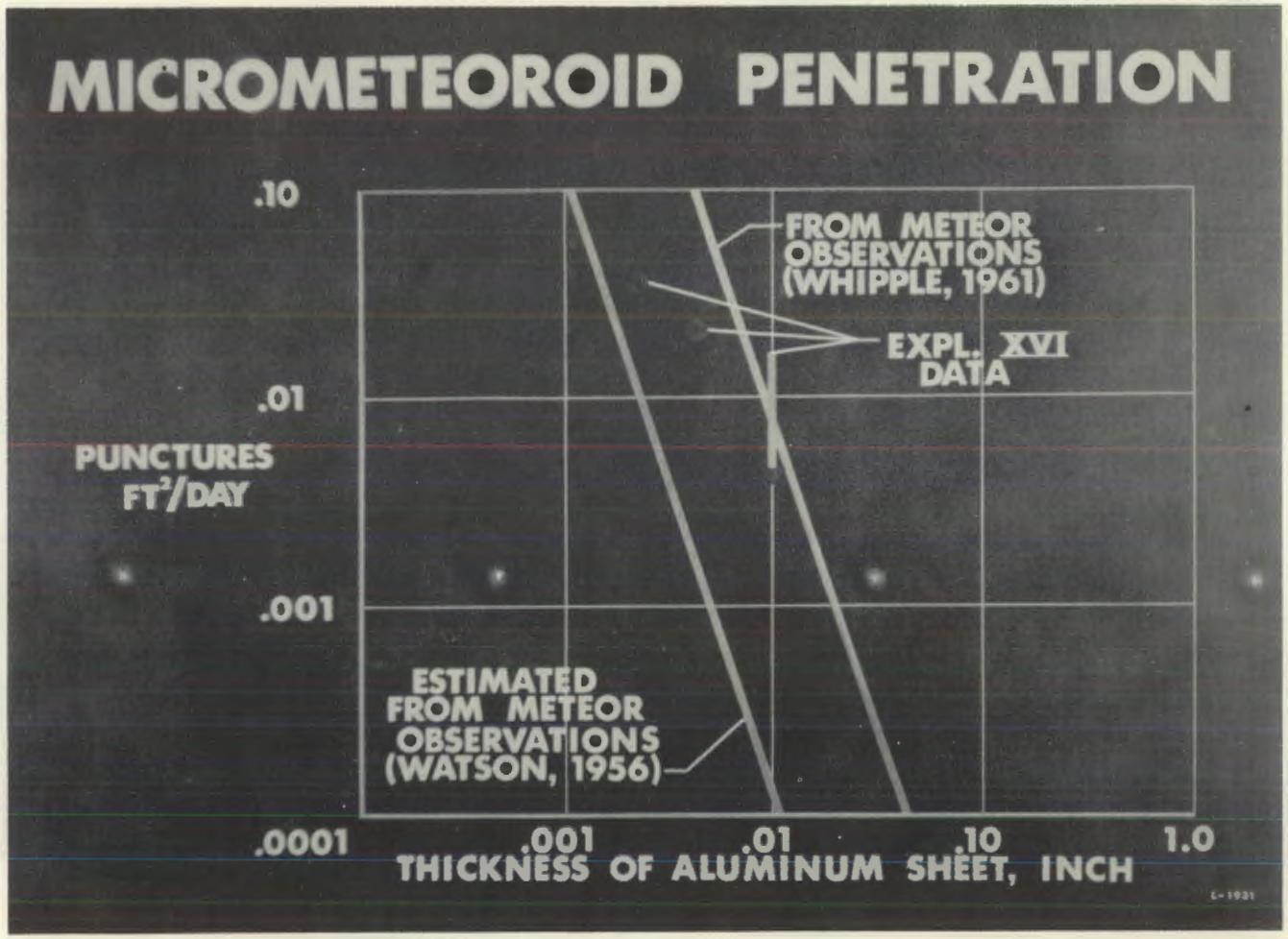


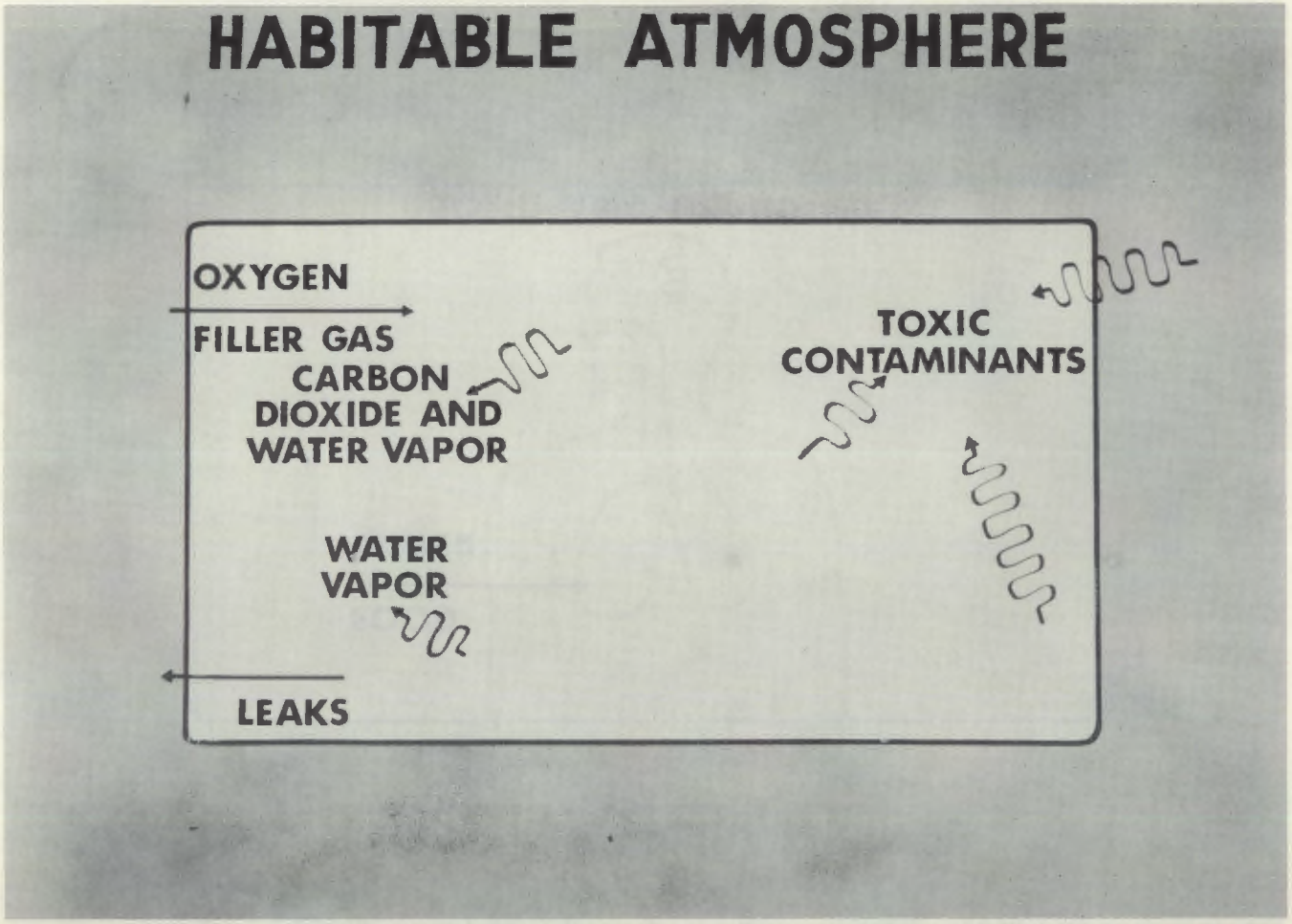
HEAT BALANCE

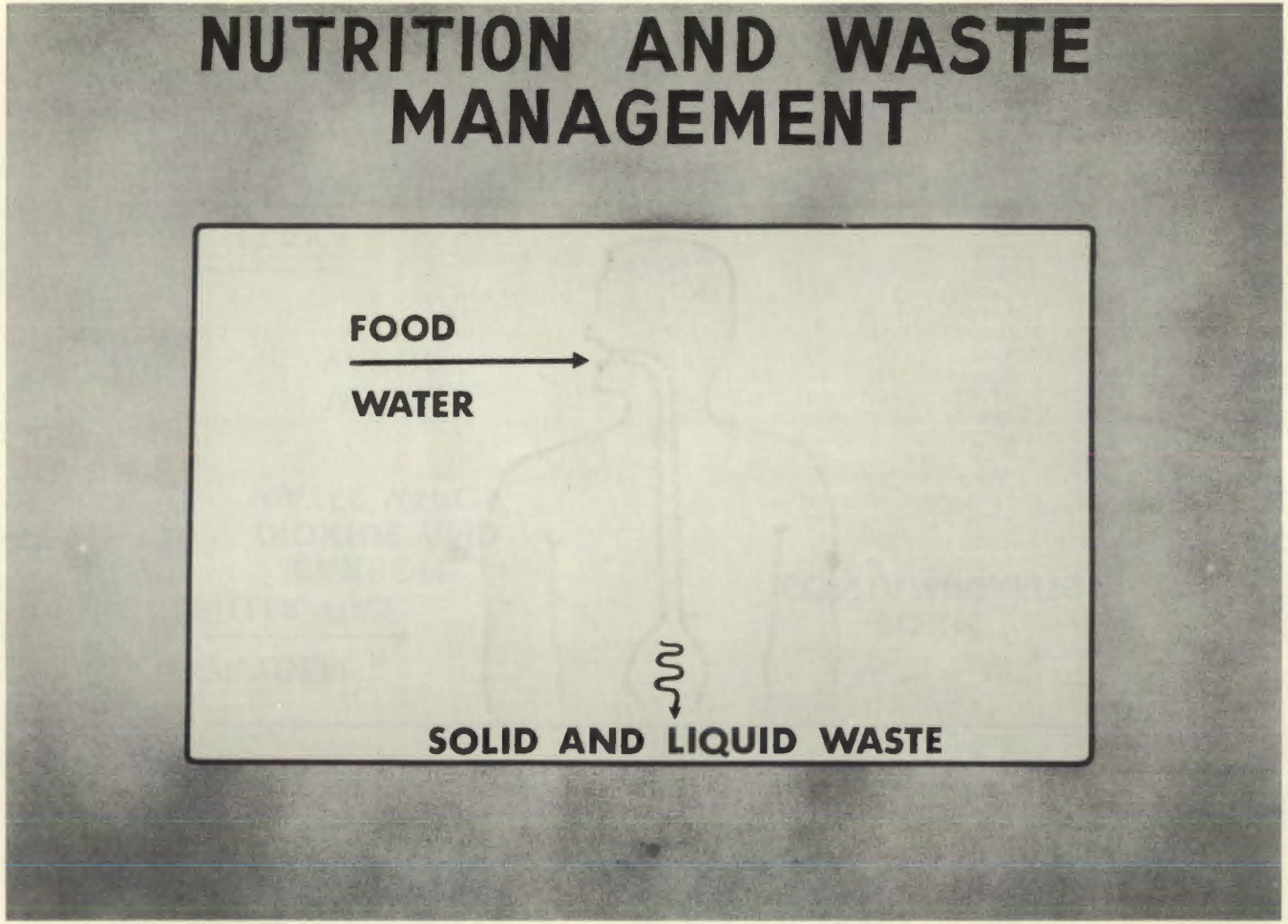


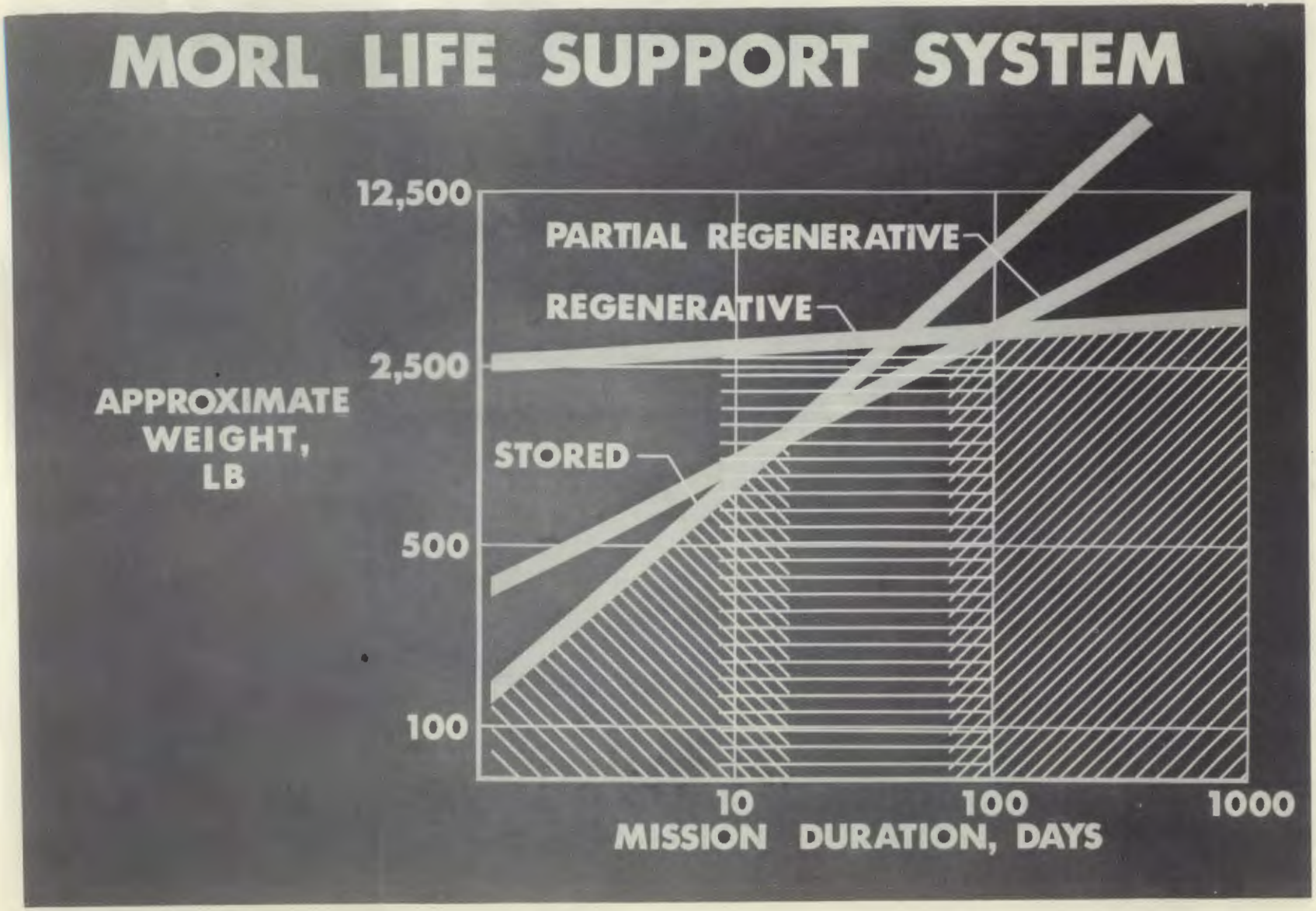

WALL TEMPERATURE
100
80
60
40
20
0
TEMPERATURE, °F
INNER WALL
OUTER WALL
0°
90°
EARTH SHADOW
90
180
270
360
SATELLITE POSITION IN ORBIT, DEG
L-1892

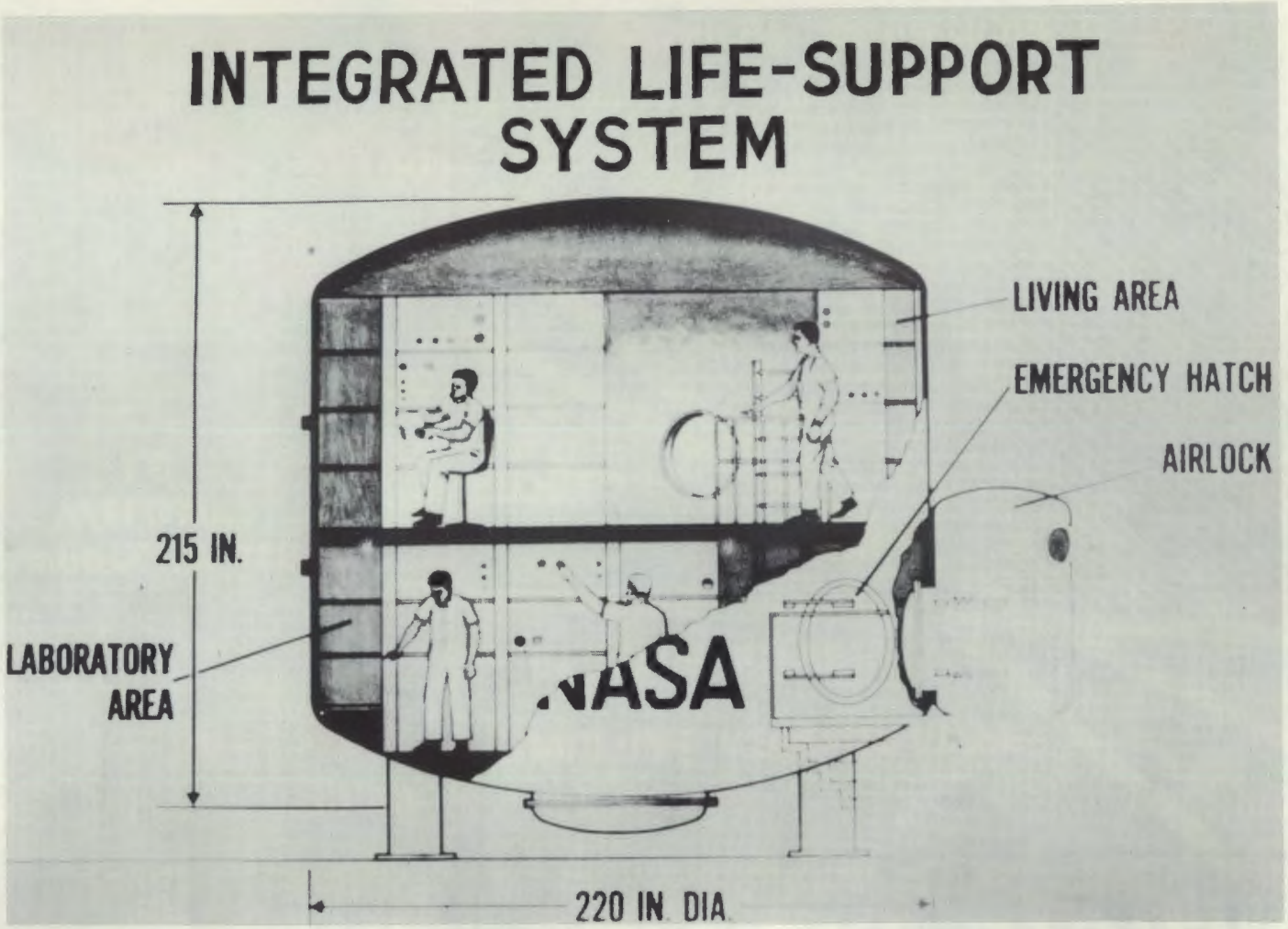

EXPLORER XVI


MICROMETEOROID PENETRATION
.10
.01
.001
.0001
PUNCTURES
FT²/DAY
FROM METEOR
OBSERVATIONS
(WHIPPLE, 1961)
EXPL. XVI
DATA
ESTIMATED
FROM METEOR
OBSERVATIONS
(WATSON, 1956)
.001
.01
.10
1.0
THICKNESS OF ALUMINUM SHEET, INCH


HABITABLE ATMOSPHERE
OXYGEN
FILLER GAS
CARBON DIOXIDE AND WATER VAPOR
WATER VAPOR
LEAKS
TOXIC CONTAMINANTS

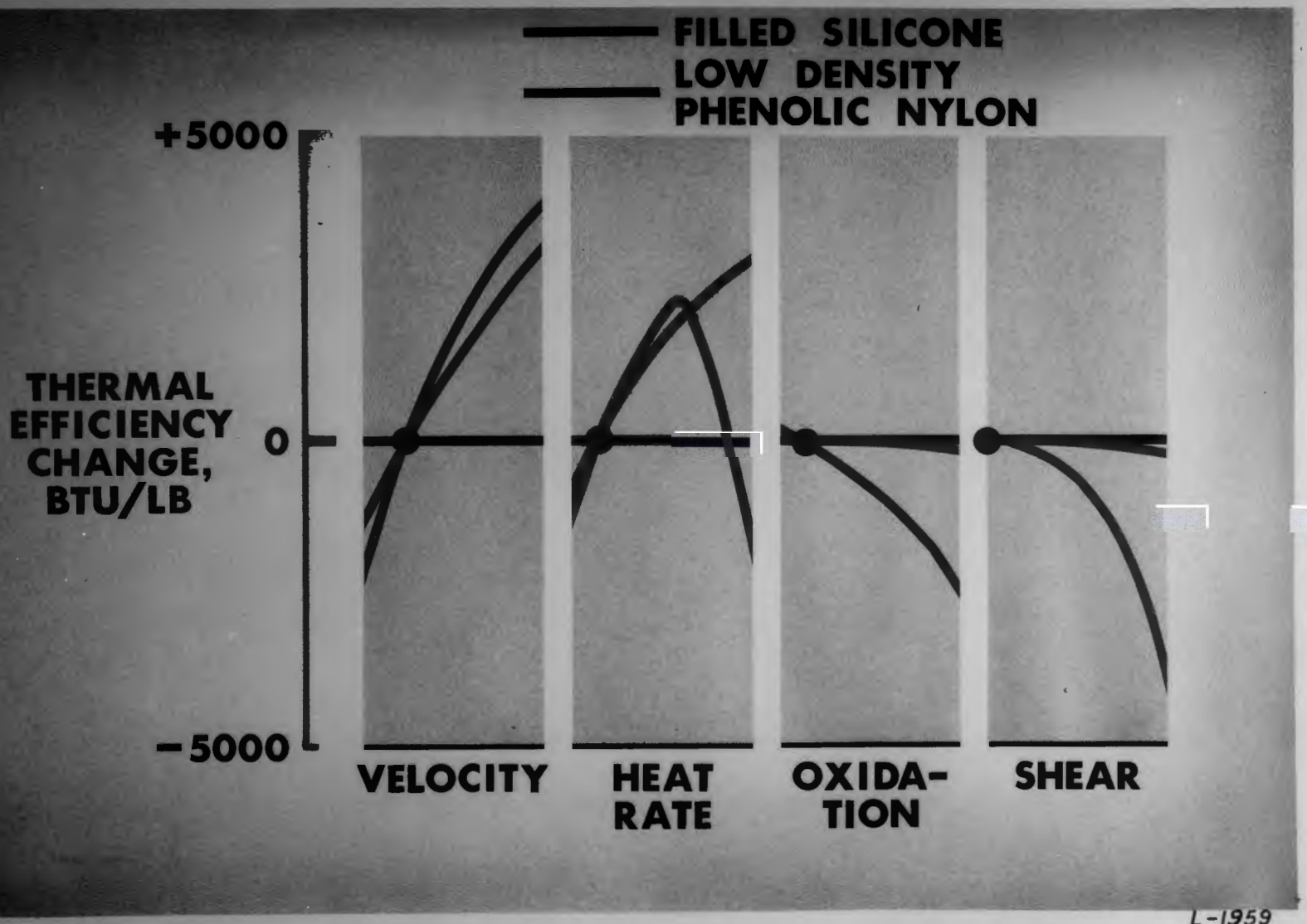

NUTRITION AND WASTE MANAGEMENT
FOOD
WATER
SOLID AND LIQUID WASTE


MORL LIFE SUPPORT SYSTEM
12,500
2,500
500
100
APPROXIMATE WEIGHT, LB
PARTIAL REGENERATIVE
REGENERATIVE
STORED
10
100
1000
MISSION DURATION, DAYS



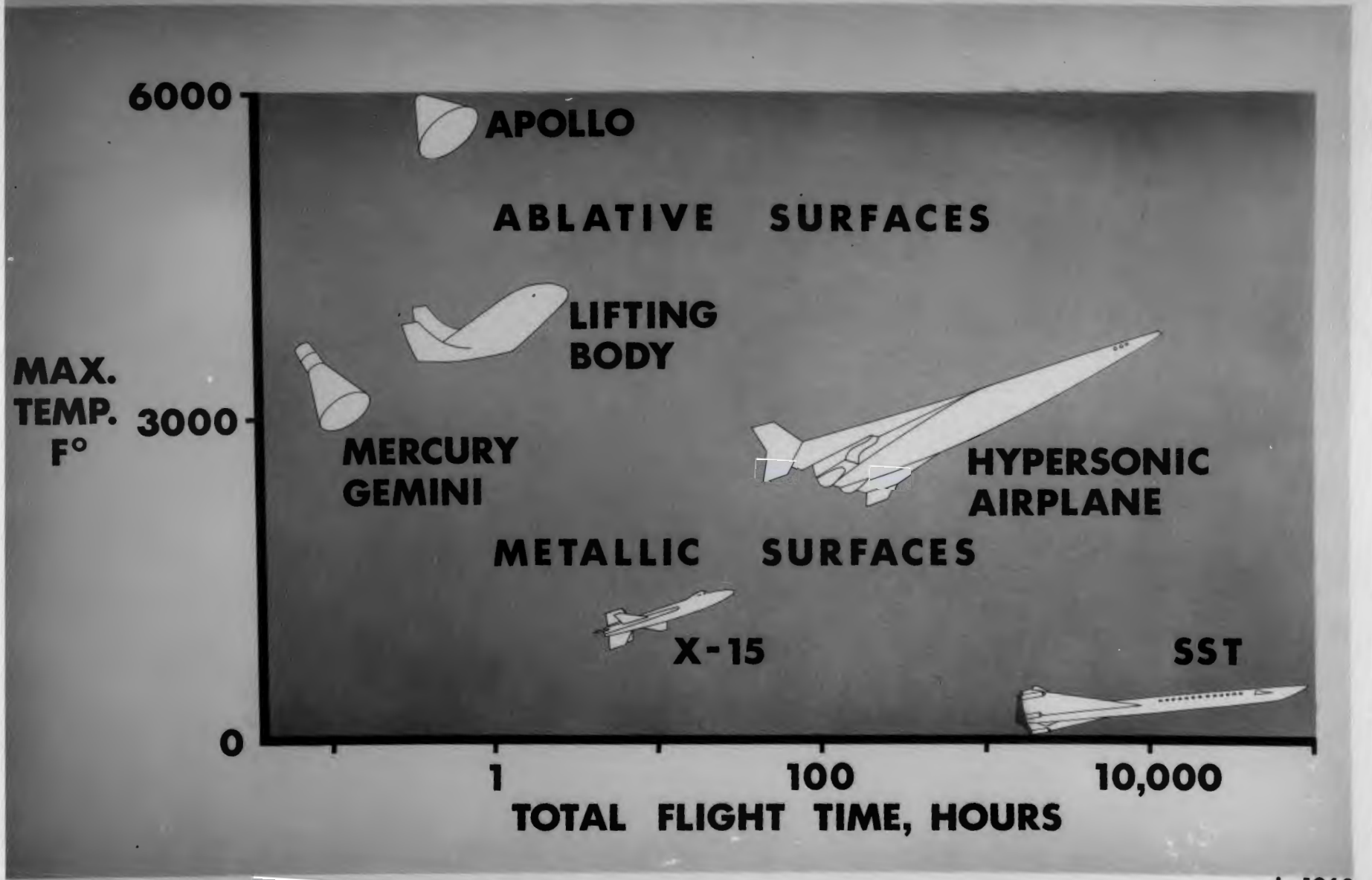
NASA-Langley, 1964

HEAT SHIELD EFFICIENCY



L-1959

AEROSPACE VEHICLE HEATING



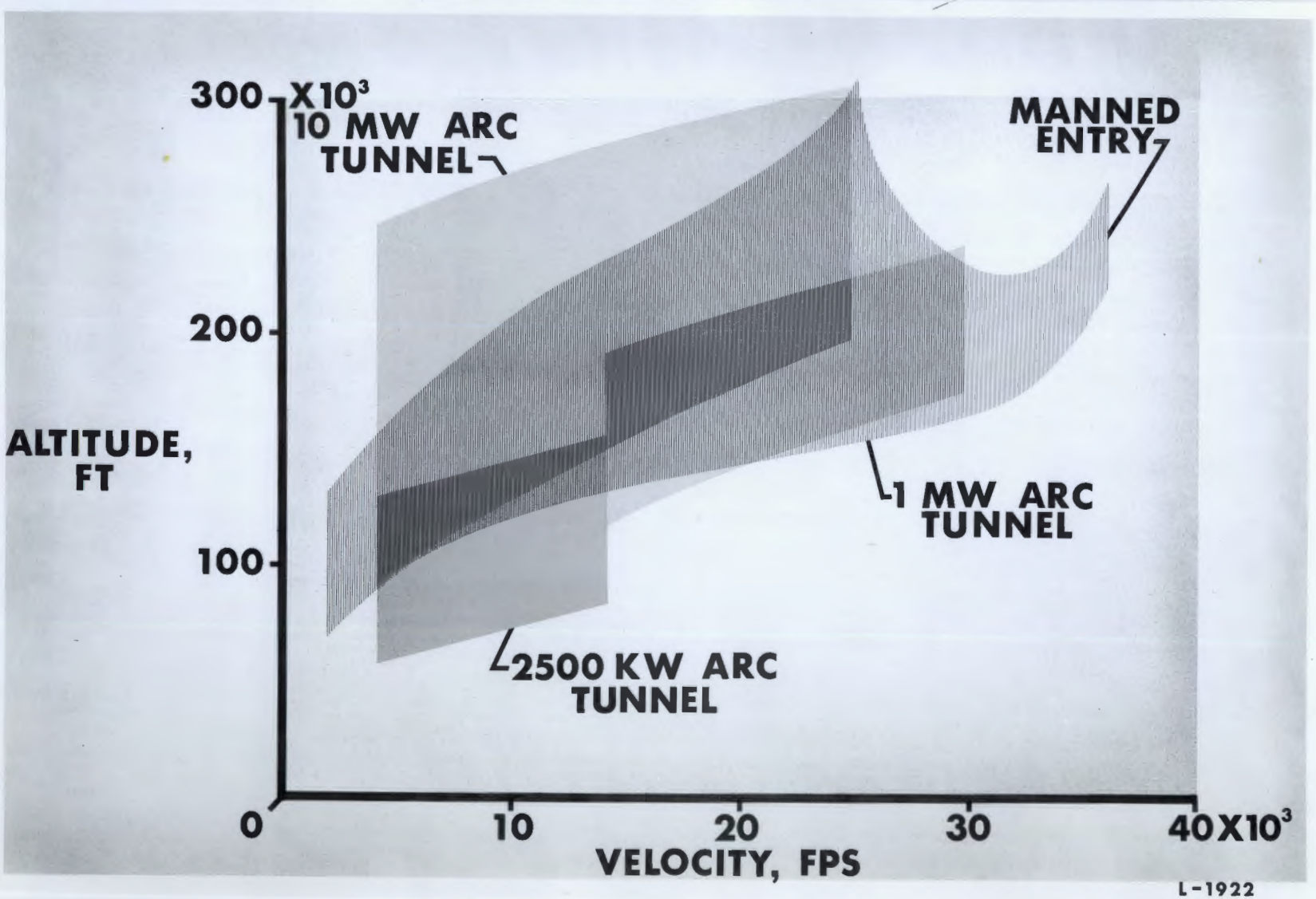
L-1960

MANNED VEHICLES FOR REENTRY AND HYPERSONIC FLIGHT

CLASS	ATMOSPHERIC RANGING	USES
BALLISTIC OR SEMI BALLISTIC	SHORT	MERCURY, GEMINI, APOLLO SPACE STATION FERRY PLANETARY RETURN
LIFTING BODY	MEDIUM	SPACE-STATION FERRY PLANETARY RETURN RECOVERABLE BOOSTER (2ND STAGE) RECON.-INSPECTION
WINGED VEHICLES HIGH L/D	LONG	RECOVERABLE BOOSTER RECON.-INSPECTION HYPERSONIC-CRUISE AIRPLANE

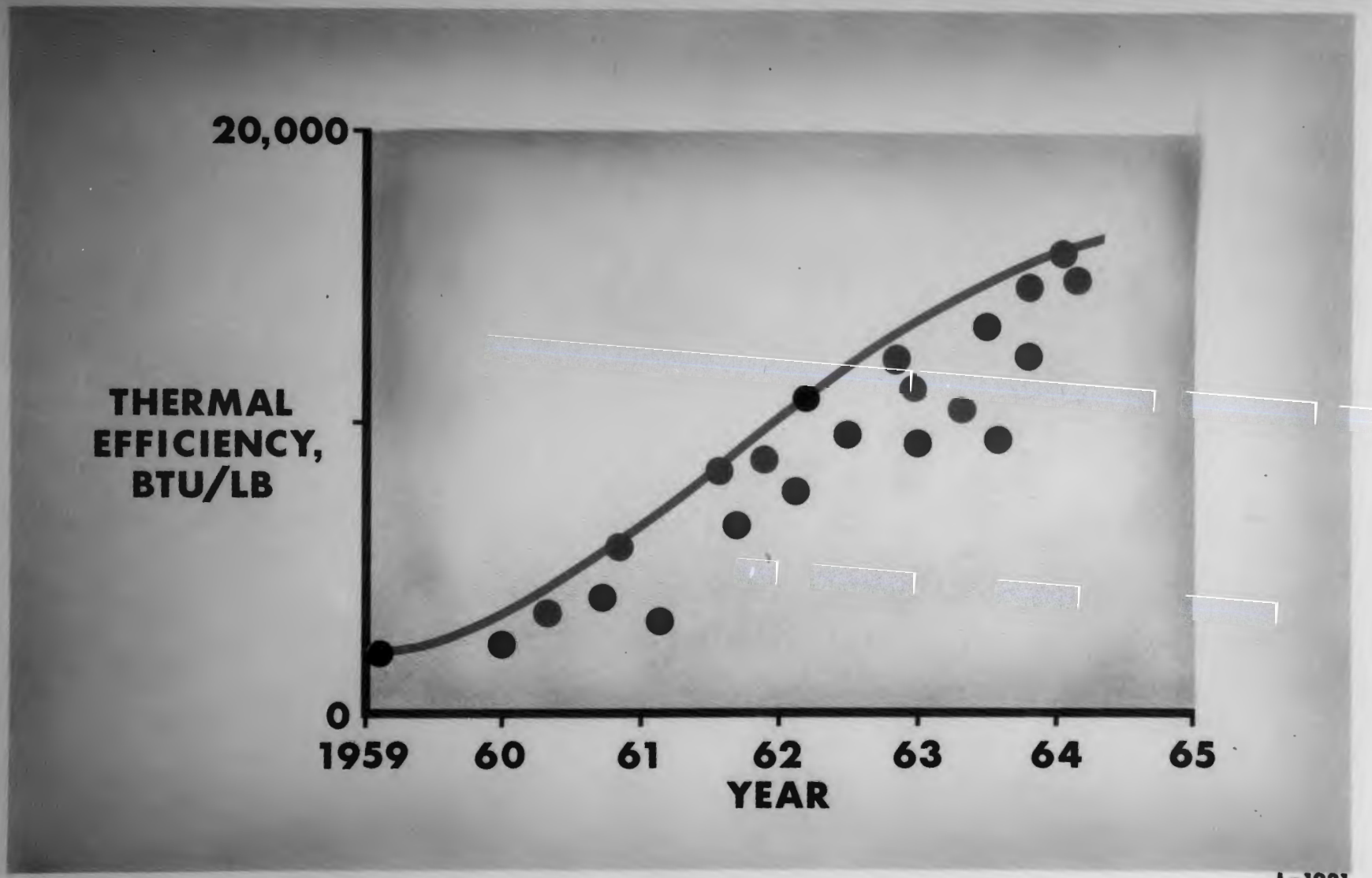
L-1957

ENTRY HEATING SIMULATION

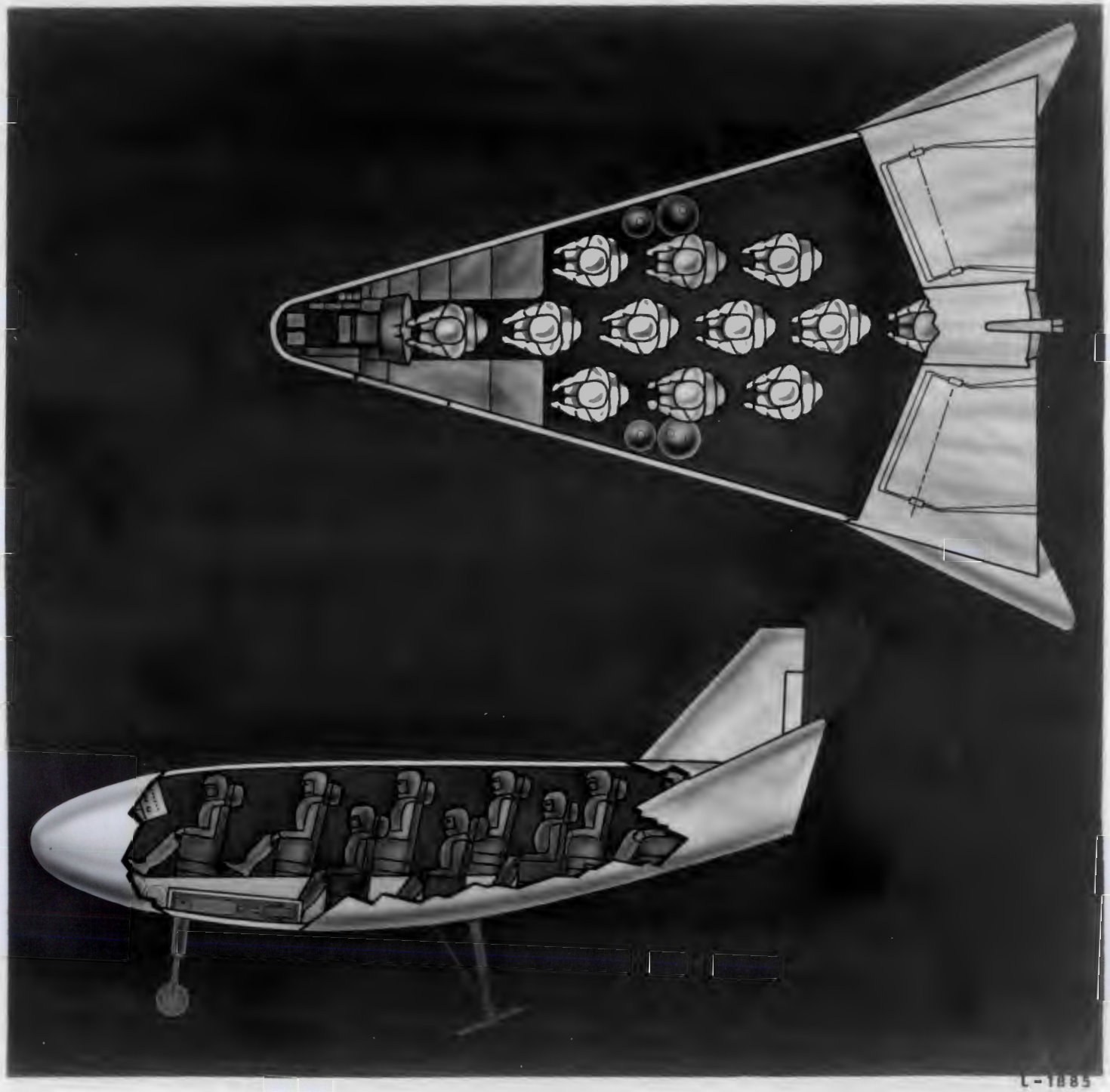


L-1922

HEAT SHIELD PERFORMANCE TREND



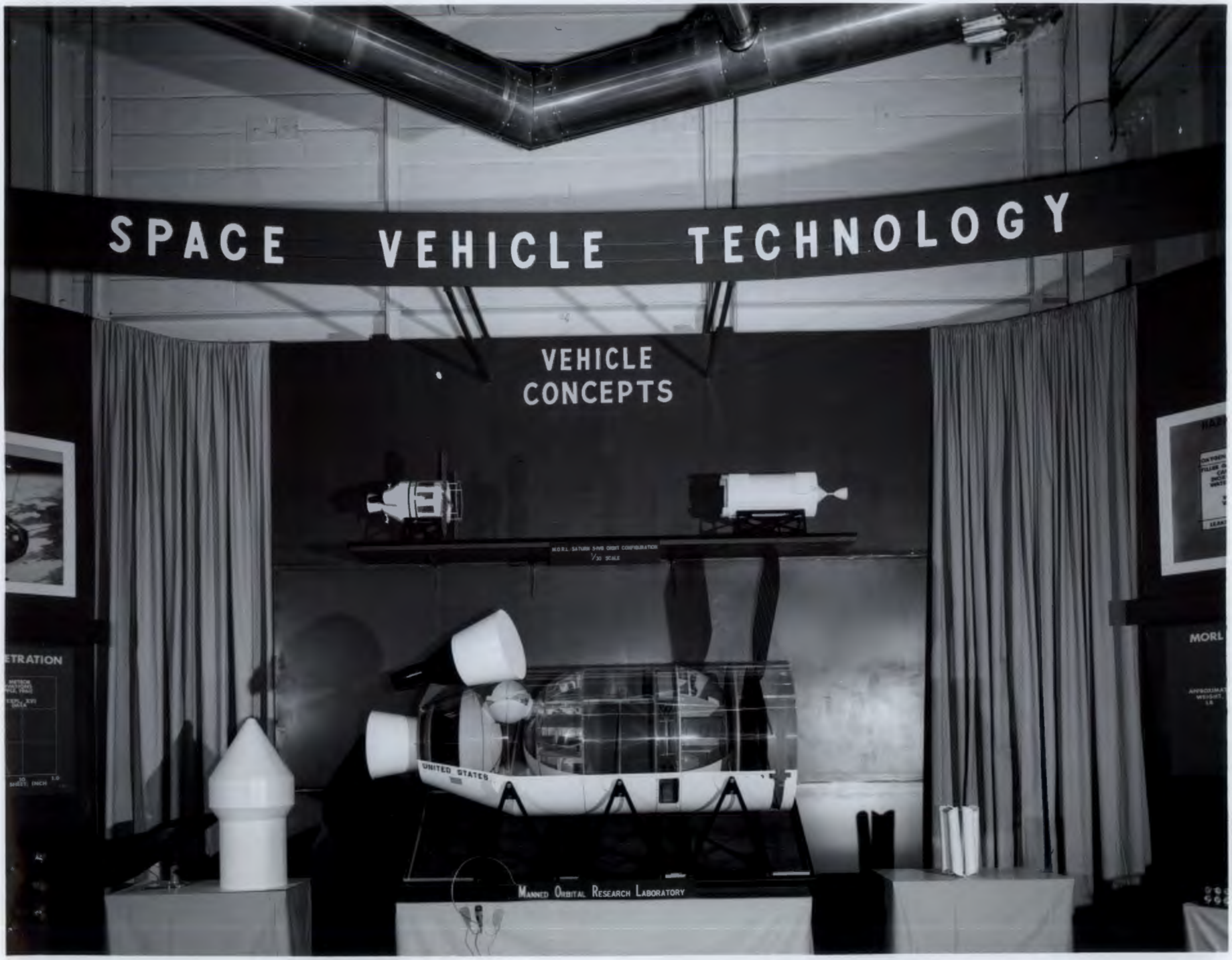
L-1921



L-1885

NASA
L-64-4858

NASA
L-64-4859

NASA
L-64-4860

NASA
L-64-4861