Shuttle crew brings science laboratory home

In space for nearly six years, the Long Duration Exposure Facility is now back on Earth, with a treasure trove of scientific information. Marsha Freeman reports.

The crew of Columbia on the thirty-third flight of the Space Shuttle, completed a scientific mission on January 20, 1990 that began on April 7, 1984, the day that a Shuttle crew aboard the Challenger deployed the 21-ton Long Duration Exposure Facility (LDEF), stocked with 57 scientific experiments that were to be exposed to the space environment for less than a year. But delays in the Shuttle schedule, and then the suspension of flights for 32 months after the Challenger explosion, left LDEF silently orbiting the Earth longer than expected. As time went on, scientists feared that if it were not recovered by 1991 it would continue to lose altitude until it descended through the Earth's atmosphere and burned up. As the Sun's activities intensified this past summer, reaching the peak in its 11-year sunspot cycle, that burn-up danger loomed nearer and nearer.

But on Jan. 12, on day 4 of the STS-32 flight, LDEF was chased down, grappled and photographed, and gently placed in Shuttle Columbia's payload bay. When Columbia finally landed early on Jan. 20, LDEF was safely home.

For years, some 200 principal scientists involved in LDEF's 57 experiments will be discovering what effects materials, components, and even living tissue are subjected to during nearly six years in Earth orbit. Damage from radiation, energetic particles, micrometeoroids, man-made debris, extreme temperature variations, and near-vacuum conditions will be seen for the first time.

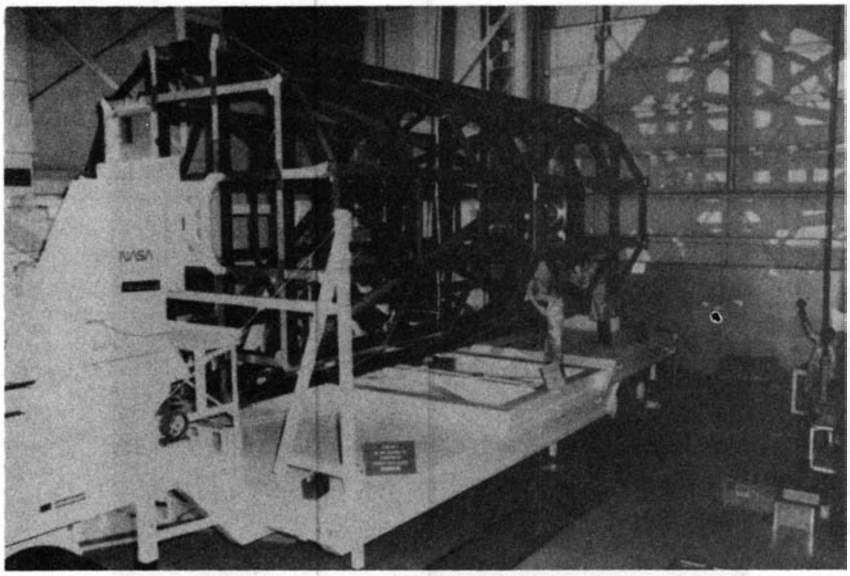
Over 40 of the experiments on LDEF will have some bearing on the design and fabrication of hardware to be deployed in space in the future. Though it is likely that, because LDEF was so late in returning to Earth, Space Station Freedom fabrication will begin before the experimental results from LDEF could be used, many other spacecraft will benefit from this long-duration stay in orbit.

Because LDEF was in space for such a long time, experiments designed to capture "rare events" such as micrometeoroid impacts have had potential fivefold increases in scientific return. Similarly, experiments to test materials for long-duration missions benefited from this longer-than-planned sojourn. It is likely, however, that other experiments which depended upon systems that only "lived" for a year after deployment will be highly degraded. The damage to some experiments, seen by the Shuttle crew and captured on film, indicated that some fragile materials did not survive well on their extended mission. These results are also important.

Racing the Sun

When scientists found out that LDEF would have to spend more years in orbit than planned, they figured out that at the expected rate of orbital decay, NASA had until 1991 to retrieve it. The Long Duration Exposure Facility was launched into an orbit of about 257 nautical miles high, or 288 statute miles. Contrary to popular notions, space is not "empty" or a pure vacuum, especially just a few hundred miles above the Earth. Both atomic hydrogen from our atmosphere and the particles from the solar wind create friction or drag on an orbiting satellite.

Then last August, the Sun's record-setting burst of activity threatened to shorten considerably the time NASA had to plan LDEF's retrieval. That month's solar activity exceeded the predicted level by 100%. A major flare on Aug. 12 bombarded five Shuttle astronauts with a high—though not dangerous—dose of radiation. The solar flare eruption was 9,000 times greater than normal. On Earth, power transmission line surges shut down electricity deliveries in Canada. Such solar flares, spewing out tons of energetic particles and energy cause the "atmosphere" inside the Sun's heliosphere to ex-



The Long Duration Exposure Facility, which carried 57 experiments into space, is undergoing final checkout at the NASA Langley Research Center, prior to shipment to the Kennedy Space Center in 1983. The 12-sided cylinder has space for up to 86 experiment trays.

pand, which increases the drag on satellites. In August, scientists predicted that if this level of activity continued, LDEF, which was then at an altitude of 217 nautical miles, could fall to 130 nautical miles by mid-January 1990.

At that time, LDEF chief scientist William Kinard estimated that since the Shuttle retrieval maneuver required the orbiter to approach LDEF from below to catch up to it, it would bring the Shuttle too close to the Earth's atmosphere to make the maneuver safe. The retrieval mission would have to be canceled. However, when the STS-32 crew grabbed LDEF last week, it had not fallen farther than to 179.5 nautical miles above Earth, because solar flares are still unpredictable.

Six years ago, the Long Duration Exposure Facility was released into orbit using the Shuttle's Remote Manipulator System, or robot arm, the same way the arm was used to pick it up. One end of the 12-sided LDEF cylinder faced toward Earth and the other out toward space as it flew in orbit perpendicular to the Earth. On Jan. 9, 1990, Shuttle Columbia was launched into an orbit which placed it 1,800 miles behind LDEF and 35 miles below it.

In order to catch up to an orbiting object and rendezvous with it, you do not go faster by flooring the gas pedal, but by orbiting at a lower altitude. Shuttle astronauts orbiting a few hundred miles above Earth circle the Earth about once every 90 minutes. A satellite in geosynchornous orbit, 22,300 miles up, takes a full 24 hours to go around the Earth. Therefore, over the first three days of STS-32, the Shuttle orbited below LDEF, closing the gap. Early on the morning of the Jan. 12 retrieval, Columbia had closed in to a distance of 16 miles, and the chase across the sky was caught on video tape by a photographer on the ground in Houston. By 9:30 a.m., the Columbia had circled around LDEF and was slowly closing in on it from above. Columbia was now upside down and flying backwards, in relation to Earth. Mission specialist Bonnie Dunbar slowly rolled the robot arm into position, and at 10:07 a.m. it was only 10 feet away from LDEF. From cameras on the robot arm and from inside the orbiter, one could see the black of space, the multi-colored, shining laboratory, the white Shuttle orbiter robot arm, and California below.

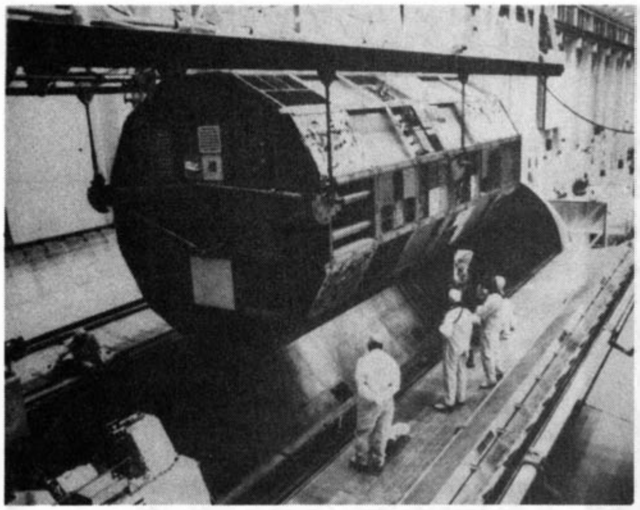
Nine minutes later the huge scientific laboratory was grappled by the arm, and for the next few hours was slowly rotated while the crew photographed each of the 57 experiments. The photographic survey was extremely important, as scientists expected that some of the most damaged, fragile experiments, may not have made the return to Earth intact. Any shaking in Columbia's payload bay, the gravitational acceleration of landing, and the reexposure of some experiments to the Earth's atmosphere, they fear, may have destroyed some specimens.

Grappling LDEF provided the opportunity to practice securing a large structure into the payload bay, which will be required over the next decades: For example, LDEF weighs 75% as much as the Hubble Space Telescope, which will have to be grappled by the Shuttle in order to be serviced while in orbit. It was important to NASA to demonstrate this Shuttle capability.

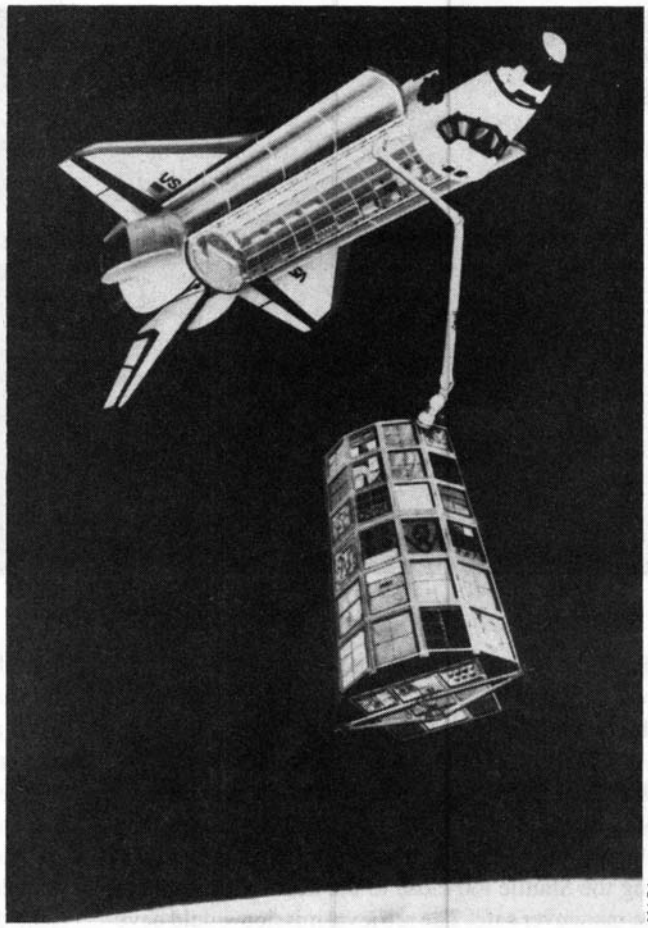
When LDEF was returned to the orbiter's payload bay, it had completed more than 32,400 orbits of the Earth and had traveled nearly the distance from the Earth to Saturn.

Remarkable scientific laboratory

The Long Duration Exposure Facility itself is an empty structure with trays facing outward to hold up to 86 experiments, arrayed on every surface of the 12-sided cylinder. On its first journey into space there were 57 different experiments on LDEF, some filling only a portion of a tray, and others needing more than one. Some experiments had detectors



At the Kennedy Space Center Operation and Checkout Building, LDEF is placed into a payload cannister for transfer to the launch pad. The 57 experiments have been placed on the structure. At the pad, LDEF was placed into the cargo bay of Challenger for launch.



This artist's conception shows the relative positions of LDEF, the Shuttle, and the Earth during the retrieval of LDEF. Relative to Earth, Columbia was flying backwards and upside-down.

placed in various parts of the structure. Through these experiments, more than 10,000 specimens were exposed to the space environment.

Each tray on LDEF is 3 by 4 feet, and up to 12 inches in depth. When it is empty, LDEF weighs 8,000 pounds. With the 57 experiments on board for this trip, the laboratory weighed more than 21,000 pounds. It fills up half the length of the 60 foot long payload bay, and it is 14 feet wide. When Columbia landed at Edwards Air Force Base in California, it was the heaviest orbiter ever to return to Earth.

The Long Duration Exposure Facility was built at the NASA Langley Research Center in Virginia, and delivered to the Kennedy Space Center in Florida in 1983, where the experiments from both around the country and the world were mated to the structure. About half the experiments on this mission were completely passive, intended only to be quietly exposed to space. The other half were active in some way. Active experiments included small, individual power sources to record data or close doors to exposure surfaces after a given period of time, and perform other experiment functions. Some of these experiments were designed to only function for a year. The laboratory carried experiments from 33 private companies, 21 universities, 7 NASA research centers, 9 Defense Department laboratories, and 8 foreign countries.

The objective of the exposure facility was to expose materials, components, detectors, and other equipment to space, and therefore the structure has no attitude control jets or engines of any kind, which would contaminate the samples. Such firings would also jolt the structure. Because it was passively stabilized, LDEF experienced very low acceleration forces.

If people do not generally remember the Long Duration Exposure Facility deployment from the Shuttle Challenger in April 1984, it is because that mission also performed the spectacular capture and repair of the Solar Maximum Mission satellite. When the astronauts examined Solar Max, they found that its thermal blankets were perforated with small holes which were believed to be from man-made debris, such as chips of paint from Shuttle orbiters. Solar Max had been in orbit for four years. Now, with LDEF, scientists will have an opportunity to examine the effects of nearly six years in space.

Science in orbit

Some things that go on in space happen only infrequently. The longer a spacecraft is in orbit, therefore, the greater the probability of capturing these rare events. A number of science experiments were designed to measure the effect of both natural and "man-made" micrometeorites.

These small bodies are less than about one-tenth of a millimeter in diameter, and scientists believe that the natural micrometeorites can yield important data about the nature, origin, and evolution of the Solar System, and the physical and chemical nature of the Earth's upper atmosphere. Many scientists surmise that micrometeorites originally came from comets. The Long Duration Exposure Facility carried a number of experiments using different materials and methods for capturing and analyzing these small bodies.

Using a multiple thin foil array, an experiment from scientists in the United Kingdom captured micrometeorites and space debris particles to determine the size, velocity, composition, and distribution of near-Earth solid particles.

In an experiment to study meteoroid impact craters on various materials, the small craters made from impacts will be the primary objects of investigation. Metals and glass materials were used in the experiment. Scientists from France expect interplanetary dust particles to form well-defined craters.

The chemistry of the micrometeoroids experiment aims to compare space samples with the same kinds of bodies that reach the surface of the Earth. The dust debris collection experiment uses multilayer thin film detectors to collect micrometeoroids for chemical analysis. This was the first opportunity for scientists to capture primary space material, and bring it back to their laboratories on Earth for thorough analysis.

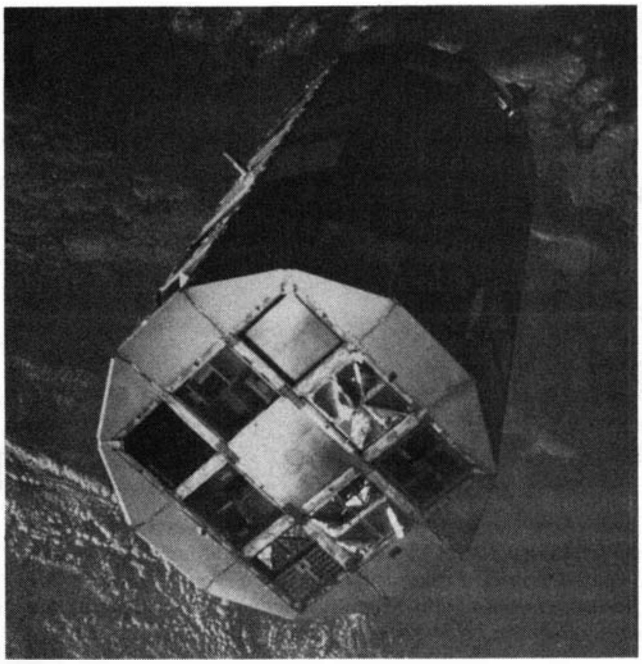
An interesting group of researchers from both the United States and four different institutions in the Federal Republic of Germany are studying the chemical and isotopic measurements of micrometeoroids, by secondary mass spectroscopy. Germanium targets covered with a thin metallized plastic foil were used to collect the residue from impacting micrometeoroids.

A second area of scientific research that also benefited from LDEF's extended stay in orbit, that is also of great practical importance, is the effect of radiation in space. One experiment was designed specifically to examine the heavy ions trapped in the Earth's Van Allen radiation belts. These are the ultra-heavy nuclei from galactic radiation, and low-energy nuclei of nitrogen and oxygen from Earth's atmosphere, and space-neon.

The number and energy spectrum-flux of trapped protons will be measured in another experiment, which will study the impact relative to human and electronic systems. These charged particles may also induce radioactivity in materials, which will be noted. The Long Duration Exposure Facility itself will be carefully examined to see if radiation was induced in the structure.

A third, related experiment will measure the energy transfer spectrum behind various configurations that might be used to shield people from radiation in space. It is clear that shielding for crews traveling beyond the Van Allen Belts is needed. The best technology with which to provide shielding in space is still under development.

Clearly a major concern is how to accurately determine the dosage of radiation living systems will be exposed to in space. This is true for astronauts who will spend months on Space Station Freedom, where they will have some protection from the Earth's Van Allen belts, and for those who will venture beyond Earth's protection, to the Moon and Mars.



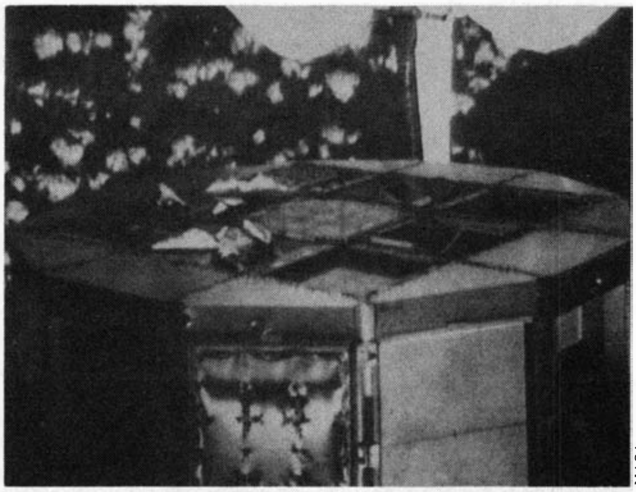
At the Columbia approached LDEF, it was clear that some of the thermal control material had peeled across the surface of at least two trays. The astronauts aboard Columbia said they looked like opened sardine cans.

Students to study 'space tomatoes'

One of the most highly publicized and important experiments aboard the Long Duration Exposure Facility is called SEEDS, for Space Exposed Experiment Developed for Students. The SEEDS experiment on this flight was precisely that—12.5 million tomato seeds provided by the George W. Park Seed Company, in South Carolina.

An equal number of tomato seeds were kept on the ground as a control group, and the Park Seed Company reports that those control seeds are sprouting well, after nearly six years. So far over 100,000 school classes have requested their packets of space and control seeds, to participate in the project. The objective of this experiment is to involve students in a "national project to generate interest in science and related disciplines."

Jim Alston and William Park from the Park Seed Company also designed their own experiment, to evaluate the effects of the space environment on the survivability of several hundred types of flower and vegetable seeds stored under sealed and vented conditions on LDEF. They will investigate the possible mutants and changes in mutation rates in the living tissue.



NASA

This photo was taken from a live television transmission from Columbia on Jan. 12, as the robot arm had just made contact with the grapple fixture on LDEF. The Teflon tape used to seal the experiment and the Kapton reflective material have peeled away from the "Heavy Ions in Space" experiment.

A second system for studying the effect of cosmic radiation on biological systems was provided by two scientists from the West German space agency. Their experiment contained biomolecules, cysts, spores, and plant seeds in a "free-flyer biostack experiment." They hope to help establish radiation protection guidelines for man and biological experiments in future space flights, by measuring the effect of cosmic radiation on living tissue.

Cosmologists also took advantage of the LDEF laboratory. The interstellar-gas experiment collected atoms to better understand nucleosynthesis, the interstellar wind inside the heliosphere, and the isotopic composition of the interstellar medium outside the heliosphere.

Ultra-heavy cosmic ray nuclei were the object of study of an experiment by scientists from Ireland and the Netherlands. By investigating the charge spectra of these ultra-heavy cosmic ray nuclei, the researchers from the two countries hope to develop a better understanding of the physical processes of cosmic ray nuclei production and the acceleration at the source regions in interstellar space.

Noted space scientist S. Fred Singer is leading an experiment to measure the distribution of masses and the orbits of interplanetary dust particles to better understand their origin and evolution. This experiment is not confined to any one tray on LDEF. There are detectors located around the entire periphery of the satellite and on both ends, which can measure the flux and the direction of the interplanetary dust.

There is no question that the LDEF experiments will provide a bonanza of unique data for space scientists. This and other information will be crucial for designing the next-generation space infrastructure, and to help answer some of the most basic questions that scientists have concerning the origins of the solar system.

Which materials can withstand space?

Earth-orbital space is a very hostile environment. Anything up there is bombarded with atomic oxygen from the Earth's atmosphere, high-energy particles from the Sun and the interstellar medium, man-made debris as small as paint chips and as large as motor parts orbiting 17,000 miles per hour, and the rapid temperature changes that occur when a spacecraft goes from night to day every 90 minutes in orbit.

Space Station Freedom is being designed to last for 30 years in orbit. The Hubble Space Telescope and other laboratories in the Great Observatories program will similarly be made to last several decades. The Moon-Mars mission of the next century will require fleets of spacecraft which will not come back to Earth, but rather will shuttle crews and cargo from Freedom to the Moon, and will be parked and maintained at the Freedom Station for years. These craft will constantly travel through and beyond the protective Van Allen radiation belts.

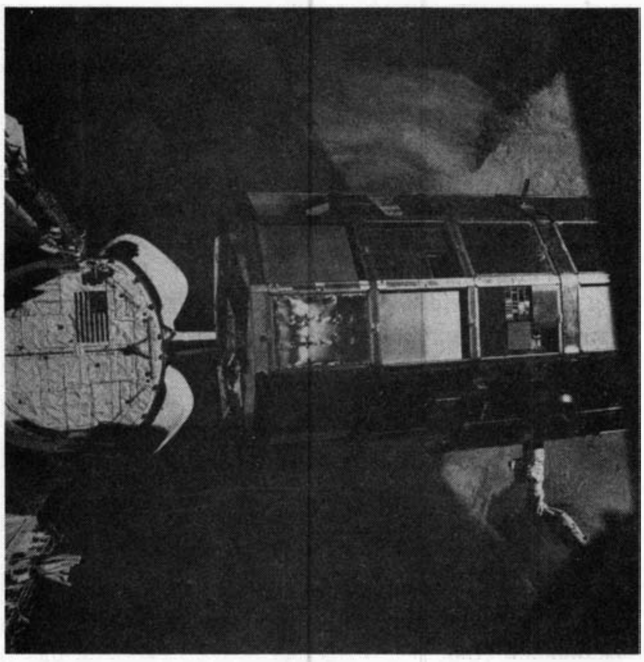
Aboard LDEF were many experiments to subject both common and new, experimental materials to the environment of space. As we found out from the experience with Solar Max, the thermal blanket materials that protect spacecraft from the rigors of space temperatures are damaged by long stays in orbit.

The atomic-oxygen-stimulated outgassing experiment on the Long Duration Exposure Facility exposed different thermal control surfaces to space to determine the effect of the oxygen impingement in producing optically damaging outgassed products. The experiment samples are located on both the leading and trailing edges of LDEF. The leading edge is being hit directly by particles coming at it, as it flies in the head-on direction. Scientists expected that the trailing edge would receive less damage, and possibly none, in the same way your face gets wet walking into a rain storm, while your back stays relatively dry.

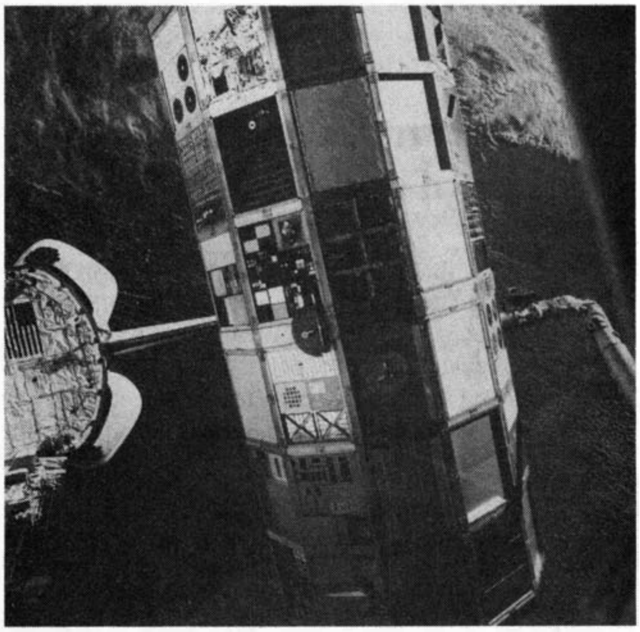
Scientists hope that the results from this experiment may help explain so-far-unexplained Skylab contamination when the United States's first space station was in orbit nearly 20 years ago.

Thin film coating interactions with atomic oxygen were studied by a team from Huntsville, Alabama, with samples also on the leading and trailing edges of LDEF. The mechanical properties of high-toughness graphite-epoxy composite material after extended exposure to space is being studied on LDEF, as are thermal expansion properties. Thermal stability is a critical factor in selecting composites for many applications such as optical platforms, and this experiment will evaluate two epoxy resins currently used in space structures.

Another experiment is studying the dimensional stability and mechanical characteristics of a mix of materials used in thermal coatings and adhesives. The thermal coatings include



In this picture, taken during the LDEF photo survey, the peeled thermal material on the end is clear. The Atlantic coast of Namibia is the backdrop of the survey.



As Mission Specialist Bonnie Dunbar slowly rotated LDEF at the end of the robot arm, Marsha Ivens photographed the experiments. The remarkable integrity of most of the trays is visible in the picture.

applications on solar reflectors and mirrors laid on aluminum and carbon substrates.

One interesting experiment by scientists at Grumman Aerospace Corporation is to test the performance of materials being considered for use in phased-array radar antenna designs. Degradation caused by thermal cycles, ultraviolet and charged particle radiation, and high voltage plasma interaction will be evaluated.

Other experiments will investigate space exposure effects of composite materials specifically being considered for large space structures, including Mylar and Teflon. Material specimens will be analyzed that are being considered for solar power components, thermal control systems, laser communication components, laser mirror coatings, laser-hardened materials, antenna materials, and electronic devices.

One experiment, from Rockwell International and the Technical University of Denmark, investigated a novel method for growing crystals in space from solutions. Space crystals are larger and more perfect than those grown under the gravity conditions on Earth, and have been particularly useful in unraveling the structure of complex biological molecules.

Two or more reactant solutions were diffused slowly toward each other in a region of pure solvent. There they were expected to react to form single crystals of substances which have important applications in optics and electronics.

Another unusual experiment was designed to assess the effect of long-term exposure to space of films, tapes, and lines that are candidate materials for balloons.

Heat pipes will be needed for the next-generation large-power systems in space to get rid of waste heat. Three experiments on LDEF specifically studied aspects of the functioning of heat pipes in microgravity using varying geometrical configurations and materials.

Power and propulsion

Today's near-Earth civilian spacecraft are powered with solar cell arrays. Dozens of solar array materials were tested on LDEF, to help increase the reliability of these energy systems, and make their lifespans more predictable.

One researcher from the NASA Lewis Research Center, which specializes in energy and propulsion research and development, tested several types of advanced and conventional solar cells. The energy distribution in the extraterrestrial solar spectrum was also measured by the experiment.

A West German experimenter designed specimens to investigate methods to control effects such as contamination, electrical conductance, and optical degradation on mirror and solar cell coatings, developed by the firm Messerschmitt-Bölkow-Blohm.

Researchers at solid rocket manufacturer Morton-Thiokol, Inc. in Utah are looking at the "space aging" of motors. Structural materials and propellants from the STAR/PAM-D series of motors were tested, as well as advanced composite cases and nozzle materials that are planned for future use. This data will be important for Thiokol to have, to decide in which applications solid rocket motors are superior.

Hermann J. Oberth: father of space flight

After a brief illness, Professor Hermann Julius Oberth, the world-recognized "Father of Space Flight," passed away on Thursday, Dec. 28, at the age of 95 in Feucht, West Germany.

In 1923, Oberth gained early fame and recognition by authoring *The Rocket into Interplanetary Space,* and later, *Ways to Space Travel.* He pioneered in rocket research and design, along with American-born Robert H. Goddard and Konstantin E. Tsiolkovsky of Russia.

Prior to World War II, Oberth began a work research program at the Institute of Technology, and during the war, he worked with Dr. Wernher von Braun (who had studied under Oberth previously). Von Braun said of Oberth, "Not only do I owe him my first introduction to the technology of rockets and space flight; he gave me the guiding star for my whole life." Always a visionary, Oberth maintained that his goal was not the launching of rockets, but "travel through space, and the exploration of the unknown."

In 1955 Professor Oberth was asked to join the rocket development center in Huntsville, Alabama where he remained for three years. During this time, he was instrumental in helping launch America's first satellite, the Explorer I, in January 1958. In July 1969, he was invited to Cape Canaveral where he viewed the launching of the Saturn-Apollo rocket taking Armstrong, Aldrin, and Collins to the Moon. This event capped the realization of his 70-year dream.

Oberth is credited with being the first to explore concepts of inertial guidance systems, life support systems, zero-gravity effects, orbiting space stations, and space mirrors. For his lifelong work as a prophet and pioneer of space flight, he is recognized in the International Space Hall of Fame in Almagordo, New Mexico.

A most prolific writer all his life, Hermann Oberth wrote numerous books, articles, scientific, and philosophical papers and studies.

The occasion of Professor Oberth's 95th birthday on June 25, 1989 saw the opening of a traveling exhibition, "Hermann Oberth: The Father of Space Flight," at the Alabama Space and Rocket Center in Huntsville, Alabama.

Professor Oberth is survived by his daughter, Dr. Erna Roth-Oberth, who lives in Feucht near Nuremberg, which is also the location of the Hermann Oberth Museum, and by his son Adolf Oberth, who lives in California.—*John Zavrel*

Electronic and optical components

Holograms in space? One LDEF experiment, designed by researchers at the Georgia Institute of Technology, will determine the effect of long-term exposure to the space radiation environment on four iron-doped lithium niobate crystal holograms. These systems, if they can withstand the space environment, would have applications in ultra-high-capacity space data storage and retrieval systems.

Filters and detectors used for various wavelengths of the electromagnetic spectrum were tested on the Long Duration Exposure Facility. Multilayer filters used for sensing atmospheric temperature and composition were tested, since understanding their optical behavior is critical to their long-term performance.

Detectors placed on spacecraft last for years. But it has not been known how the degradation of the detector materials affects their performance. This is crucial, because readings may reflect changes in the material more than changes in the phenomena the detector is supposed to be measuring. Questions of this kind have arisen, for example, in the detectors analyzing the supposed "hole" in the ozone layer, which may be the result of faulty measurements.

Pyroelectric infrared detectors, used to monitor air pollution and used in the thermal mapping of the Earth, were exposed on LDEF so that space effects could be understood and factored in to ensure the validity of measurements.

In order to qualify new ultraviolet optical components, it is useful to know the effects the space environment has on components such as thin films, gas filters, photocathodes, and crystal filters. French researchers carried out such an experiment on LDEF.

In the future, fiber optics will be used in space and aboard space facilities, just as this technology is replacing standard communications transmission systems on Earth today. Scientists from France exposed fiber optic waveguides to space on LDEF. The results will allow the researchers to design laboratory tests that simulate space radiation effects for further study.

Scientists from the University of California's Jet Propulsion Laboratory tested fiber optic data transmission equipment for degradation, and a researcher from the Air Force Weapons Laboratory at Kirtland Air Force Base, New Mexico, carried out an experiment to assess the survivability of radiation hardened fiber optic data link designs. These test results will allow the design of new systems which have already benefited from being "tested" in space.

LDEF chief scientist William Kinard expects that scientists will be examining the results from their experiments for the rest of this decade.

First glance after six years

While the Columbia was still in orbit, scientists on the ground were peeking at LDEF through the eyes of the cameras on the Shuttle. Kinard stated that there appeared to be no structural damage to LDEF itself.

As the Columbia approached LDEF it was clear that thermal covers over two trays had peeled back, and were described by the astronauts as resembling a half-opened sardine can.

As expected, on the leading edge of LDEF, which was flying head-on into the oncoming particles and radiation, the trays looked as if they had sustained more damage than the experiments along the lateral sides of the cylinder. The thin film experiments looked as though they had been substantially eroded by the atomic oxygen in orbit.

The crew reported that they saw pieces of material they could not identify, floating in formation alongside LDEF. Kinard could not tell if these pieces had come off the facility's experiments when the laboratory was slightly jostled on grapple by the robot arm, or if the pieces had broken loose earlier and were orbiting along with the structure for a period of time.

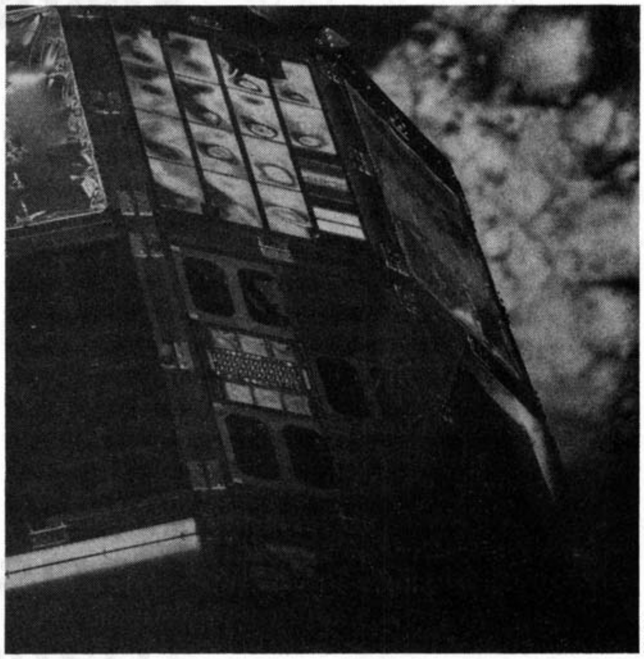
The scientists were surprised to find that there was not much difference in damage between the end of LDEF facing outward, toward space, and the end that faced in toward Earth. They had expected the Earth end to sustain more damage.

NASA has put together four major teams of researchers to examine LDEF immediately upon return. One will look at the entire spacecraft for meteoroid and debris damage. The radiation team will measure the background radiation LDEF endured, and check for induced radiation in the whole facility.

The materials group will check the overall damage on various kinds of materials experiments, and the systems team will look at the power, mechanical, and electronic systems, to see how they performed.

After that initial survey, the trays will be removed very slowly and carefully from LDEF, at a rate of only three per day. They are being returned to the principal investigators for study, and at the end of February, results of these first looks will be released. Six months after that, investigators will present a more comprehensive picture of what it meant to spend nearly six years in space.

Kinard stated that LDEF could be turned around and outfitted with new experiments in about 18 months. Due to the tight Shuttle schedule and the demands that will be made on the Space Transportation System once Space Station Freedom begins deployment, it is not likely that the Long Duration Exposure Facility will fly again. "The Space Station may become our next long duration facility," Kinard stated. But the results from LDEF will have benefits for every kind of spacecraft—unmanned, remote sensing, military, as well as manned—that will be designed in the future. The systems developed for LDEF will likely be used for, perhaps smaller, LDEF-like unmanned structures to continue testing the long-term effects of space. Perhaps Space Station Freedom will have such a facility flying free alongside it in the future.


NASA

In this closeup from the LDEF photographic survey, an experiment from the NASA Johnson Space Center is at the center top, and just below it is an experiment from France. In the top tray, the shiny surfaces catch the Earth's clouds and reflect them back to the crew.

The Shuttle Columbia flight successfully ended a most remarkable, nearly six-year science experiment. It took advantage of the unique capability of the Space Shuttle to bring astronauts into orbit in order to capture spacecraft out there, and to bring payloads back to Earth.

This year another Shuttle crew will deliver the Hubble Space Telescope into orbit, and later crews will grapple it with the robot arm to perform maintenance, make any necessary repairs, and update its component technology. If it were absolutely necessary, the Shuttle could also bring it back to Earth.

This year's Hubble Telescope launch will open the era of long-duration, nearly permanent operational facilities in space. The Great Observatories program will eventually be comprised of four large telescopes, each looking into space through a different part of the electromagnetic spectrum. Scientists will see things they could never see from the surface of the Earth.

Freedom will be the first space station designed to give man the opportunity to live and work in space for decades.