LDEF is coming home! The National Aeronautics and Space Administration's (NASA) Long Duration Exposure Facility (LDEF), which has been orbiting Earth since the spring of 1984, will be retrieved by a Space Shuttle crew in late 1989. LDEF is the first NASA program designed to test the performance of spacecraft materials, components, and systems that have been exposed to the space environment for a long time. LDEF is an international treasure with unprecedented data that will be invaluable in the design of future spacecraft, such as Space Station Freedom, which must operate for many years in space. LDEF science experiments will provide new insight in understanding our cosmic origins.

The LDEF program was approved by the NASA Office of Aeronautics and Space Technology (OAST) in Washington, D.C., and is managed by the Langley Research Center (LaRC) in Hampton, Virginia. The LDEF structure, built at LaRC, was shipped to the Kennedy Space Center (KSC) in Florida in 1983 for experiment integration in preparation for launch.

On April 7, 1984, the spacecraft, which is the size of a small school bus, was deployed by the crew of the Space Shuttle Challenger. Original mission plans called for retrieval of LDEF by a Shuttle in 10 months, after which the experiments would be returned to the principal
investigators for data analysis. However, LDEF retrieval was rescheduled for the fall of 1986 because of orbiter launch requirement constraints. With the loss of the Space Shuttle Challenger in January 1986, Space Shuttle launches were suspended until September 1988.

Because LDEF has remained in space for more than 5 1/2 years, as opposed to the originally planned 1-year mission, its value has been substantially enhanced. The LDEF extended mission will reap the benefits of a five-fold increase in science and technology experiment data.

New Dimension in Space Experimentation

LDEF is the first spacecraft designed to place experiments in space for a long period of time and then return the experiments to Earth for comprehensive laboratory analysis. This concept not only provides a very cost-effective method for conducting experiments in space, but also substantially enhances the data analysis capability by returning the experiment to the laboratory for examination. This capability adds a new dimension to space experimentation. LDEF also possesses the unique feature of passive stabilization, which provides its required orientation in space. Since no attitude control system jet firings are required, LDEF is subjected to the lowest acceleration forces and contamination levels of any spacecraft to date. These factors are important assets when conducting science and technology experiments in space.

The LDEF, ready for installation of experiment trays, undergoes final checkout at the NASA Langley Research Center prior to shipment to Kennedy Space Center.
LDEF Experiments

LDEF carries 57 science and technology experiments; these experiments represent more than 200 investigators, 33 private companies, 21 universities, 7 NASA centers, 9 Department of Defense laboratories, and 8 foreign countries. A list of experiments, with investigators and their sponsoring organizations, is attached.

LDEF experiments cover a broad spectrum of science and technology investigations. LDEF science experiments include issues ranging from the evolution of galaxies to the effects of radiation on the ability to live and work in space. LDEF technology experiments measure the effects of long duration exposure to the space environment on spacecraft systems, that is materials and structures, power and propulsion, electronics, and optics.

Approximately one-half of the LDEF experiments use power either to record data or to provide experiment control functions. The remaining experiments are passive and require only exposure to space.

An unparalleled quantity of micrometeoroid material will be captured and returned to Earth, and its chemical composition will be determined. Since this material was present during the formation of the solar system, knowledge of its chemical composition will increase the understanding of the processes involved in the evolution of the solar system.

The impact of space radiation on living organisms is another area being investigated. There is much to be learned about the nature of the environment of outer space and the effects of prolonged exposure on living organisms. LDEF science experiments gather data on radiation intensity and its effect on living organisms, that is plant and animal cells.

A permanently orbiting Space Station Freedom may itself become radioactive, as a result of the exposure of materials to cosmic radiation. The LDEF facility and experiments will provide unprecedented data on the magnitude of this induced radioactivity in materials during prolonged exposure to space. This information is of interest to bioengineers and scientists, who are concerned with effects on the crew and instrumentation on Freedom. Space radiation dosage has cumulative effects on people and can lead to medical complications. It is critical to understand exposure of radiation levels to humans in space. Radiation will ultimately be a deciding factor on the duration of manned activities in space.

A Nationwide Student Science Experiment

The Space Exposed Experiment Developed for Students (SEEDS) offers a wide variety of opportunities for student experiments. Investigators will provide a total of 12.5 million tomato seeds, packaged in seed kits, to students from the upper elementary through the university level. They will have the unique opportunity to study the effects of long-term space exposure on tomato seeds. Studies may include germination rates, seed embryo development, tropic reactions, and fruit products. Students may study the impact of changes in environmental factors such as water, humidity, soil, and pollutants. University students may choose to design their own experiments, individually selecting controls and variables. The program encourages active student involvement and a multidisciplinary approach; this

Science Experiments

An interstellar gas experiment provides insight into the formation of the Milky Way galaxy by capturing and analyzing its interstellar gas atoms. LDEF cosmic radiation experiments investigate the evolution of the heavier elements in our galaxy.
approach allows students to design individual experiments and to be engaged in decision making, data gathering, and reporting of final results. For further information, educators who wish to obtain SEEDS kits and participate in this program should contact the Educational Programs Office, NASA Headquarters, Washington, D.C. 20546.

Packaged tomato seeds being placed in canisters for the Space Exposed Experiment Developed for Students (SEEDS).

Materials and Structures Experiments

Before substantial investments are made in designing and building spacecraft that require extended lifetimes, it is desirable to understand the behavior of materials exposed to the space environment. LDEF experiments collect data on the behavior of thousands of materials associated with the design of spacecraft structures, thermal control systems, power systems, optics, electronic systems, and propulsion systems exposed to environmental effects of radiation, vacuum, extreme temperature variations, atomic oxygen, and collision with space matter. Since the LDEF mission will provide the only source of data to measure effects of prolonged space exposure on spacecraft materials, unique information will be provided for the design of future spacecraft with extended lifetimes.

Based on LDEF results, spacecraft structural materials, which have experienced little or no change to their structural properties, will be used to ensure the structural integrity of future spacecraft. Thermal control coatings will be chosen with the assurance that their thermal properties would not degrade and jeopardize a spacecraft because of excessive heating or cooling. Solar array power systems will employ solar cells whose performance characteristics have been demonstrated over long periods of space exposure. Optical instruments will take advantage of filters and components whose performance have been confirmed. In essence, spacecraft and spacecraft systems will be designed using materials that have been validated for long duration space exposure; the costly replacement of unproven spacecraft hardware will therefore be minimized.

Power and Propulsion Experiments

LDEF provides an opportunity to study the effects of extended space exposure on the design of solar array power systems. Solar cells, used by solar array power systems, have proven to be a very effective means of generating spacecraft power. As experiments become more complex, so do their power requirements, and further demands are placed on the efficiency and endurance of solar cells. The effects of exposure to the space environment on the performance of a wide variety of solar cells and associated components are recorded by LDEF.

Since some spacecraft require exposure of solid rocket motors to the space environment for a considerable length of time prior to their operation, the effect of this exposure on their performance must be understood to ensure successful operation. Solid propellant materials and propulsion system components on LDEF will be examined to study this phenomenon.

Optics and Electronics Experiments

Degradation of optical systems that have been in space for a long time compromises the integrity of the data being measured. LDEF experiments are designed to investigate the effects of prolonged space exposure on optical system components, which include optical filters, coatings, glasses, detectors, and optical fiber transmission links.

LDEF experiments also contain optical components identical to those on spacecraft now taking measurements in space. An example is the experiment carrying Earth and solar sensors identical to those on the Earth Radiation Budget Experiment (ERBE) on the Nimbus 7 spacecraft. Upon return of the LDEF experiment to the
laboratory, the performance of these components will be evaluated and the information will be used to correct any bias which may have occurred in the 10 years of accumulated ERBE data.

An understanding of the performance of the space exposed electronic systems is critical in ensuring their successful operation. LDEF experiments will provide information on the effects of more than 5 1/2 years of exposure to the space environment on the operational characteristics of its electronic systems and components. This information will provide an important data base for design of electronic systems used on the next generation of spacecraft.

A unique process for growing crystals in solutions, which takes advantage of the microgravity conditions provided by LDEF, is used to grow high purity crystals with unique electrical properties applicable to electronic circuits. The microgravity conditions for this LDEF crystal growth experiment are the most conducive, to date, to the growth of high purity crystals.

LDEF Structure and Experiment Systems

LDEF is a 12-sided cylindrical structure that is 30 feet long, 14 feet in diameter, and weighs 22,000 pounds. The spacecraft carries 86 trays, mounted around the periphery and on each end of the structure, in which 57 self-contained experiments are housed.

Several systems which support experiment operations have been provided by NASA for investigator use. Lithium-sulphur dioxide batteries are provided for experiments requiring power. The Experiment Power and Data System (EPDS) is provided to record experiment data measurements. Since no data are telemetered to Earth, no experiment data will be available until LDEF is retrieved. An Experiment Exposure Control Canister (EECC) is provided for experiments requiring controlled exposure. The EECC has a sealable drawer that can be opened and closed at programmed times.

The LDEF and its experiment support systems demonstrate the LDEF philosophy of simplicity. An experiment, with supporting systems, is placed in an experiment tray (3 feet x 4 feet and up to 12 inches in depth). The tray is then attached to the periphery of LDEF, and LDEF is placed in Earth orbit. After retrieval of LDEF, the experiment tray is removed from the spacecraft, and the experiment is removed from the tray and given to the investigator for analysis.
LDEF Mission

LDEF Launch

The Space Shuttle Challenger and its crew of five—Commander Robert Crippen, Captain, USN; Pilot Dick Scobee; and Mission Specialists George Nelson, Terry Hart, and James van Hoften—were launched from Kennedy Space Center on the morning of April 6, 1984. After a day of unpacking and checking out systems, the STS-41C crew deployed LDEF on the morning of the mission's second day.

Placing LDEF in orbit was a relatively simple operation. Terry Hart used the manipulator arm to latch onto a grapple fixture protruding from LDEF's side as it lay in the cargo bay. This activated the experiments equipped with self-contained power supplies. Hart then attached the manipulator arm to a second grapple fixture, removed LDEF from the cargo bay, placed the spacecraft in its proper orientation, and released it into an Earth orbit of 257 nautical miles with an inclination of 28.5°.

LDEF Retrieval

The Space Shuttle Columbia, with a crew of five, is scheduled to retrieve LDEF during the STS-32 mission. STS-32 will be led by veteran commander Daniel C. Brandenstein, Captain USN. James D. Wetherbee, Lieutenant Commander, USN, will pilot the orbiter, with Bonnie J. Dunbar, G. David Low, and Marsha S. Ivins on board as mission specialists. Dunbar will operate the manipulator arm to retrieve LDEF while crew member Ivins photographs the LDEF during retrieval operations. Once the manipulator arm grasps LDEF, the crew will make the first set of LDEF observations after its long stay in orbit by photographing and providing visual inspection of each LDEF experiment tray as the spacecraft is returned to the payload bay. These visual and photographic operations will document the condition of LDEF experiments in space and will also be used to assess the effects of retrieval operations on the experiments. LDEF will remain in the orbiter bay until the Shuttle returns to KSC via the ferry flight from its landing site at Edwards Air Force Base, California.

Considerable precautions will be taken to minimize and measure contamination during LDEF operations, that is orbiter rendezvous, LDEF capture, orbiter in-space operations, orbiter reentry, ferry flight operations, and KSC operations. Once back at KSC, LDEF will be examined by the experiment investigators and investigation groups composed of specialists in the meteoroids and space debris, materials, spacecraft systems, and radiation disciplines. This initial examination of LDEF, prior to experiment tray removal, will focus on the interrelationship of all experiments and the LDEF structure. Based on these examinations, the subsequent steps necessary to maintain data integrity and optimize data return will be established and incorporated into existing KSC operations plans. The experiment trays will then be removed from the LDEF structure, and the experiments will be distributed to the investigators for data analysis.
Benefits of the Extended LDEF Mission

LDEF experiments were designed for a 1-year mission in space. Although a few experiments have suffered some degradation because of their increased exposure to the space environment, the large majority of experiments have been substantially enhanced. LDEF promises a treasure of information.

The science experiments hold exciting revelations regarding evolution of the cosmos and biological effects of long-duration space exposure as they relate to the presence of humans in space. LDEF technology experiments will establish a data base for use in designing spacecraft, such as Space Station Freedom, which must operate for many years in space.

LDEF experiments offer an exciting opportunity to add to the exploration and understanding of space.

Future Applications

The LDEF structure, designed for reuse, may be available for use on future LDEF missions, or it could be reconfigured to support a specific investigation, such as a series of cosmic radiation experiments. Possible future missions include a series of LDEF structures, which would remain in orbit up to 10 years, with removal and replacement of experiment trays by Shuttle crew members. The LDEF concept offers unique capabilities for conducting experiments in space and has a broad range of applications.
LDEF Experiments and Principal Investigators

Materials, Coatings and Thermal Systems

GROWTH OF CRYSTALS FROM SOLUTIONS IN LOW GRAVITY - Dr. M. David Lind, Rockwell International Corporation, and Kjeld F. Nielsen, Technical University of Denmark.


INTERACTION OF ATOMIC OXYGEN WITH SOLID SURFACES AT ORBITAL ALTITUDES - Dr. John C. Gregory, University of Alabama, and Dr. Palmer N. Peters, NASA Marshall Space Flight Center.

INFLUENCE OF EXTENDED EXPOSURE IN SPACE ON MECHANICAL PROPERTIES OF HIGH-TOUGHNESS GRAPHITE-EPOXY COMPOSITE MATERIAL - Dr. David K. Felbeck, University of Michigan.

EFFECT OF SPACE ENVIRONMENT ON SPACE-BASED RADAR PHASED-ARRAY ANTENNA - Richard J. Delasi, James B. Whiteside, Martin Kesselman, Ronald L. Heuer and Frederick J. Kuehne, Grumman Aerospace Corporation.

SPACE EXPOSURE OF COMPOSITE MATERIALS FOR LARGE SPACE STRUCTURES - Wayne S. Slemp, NASA Langley Research Center.

EFFECT OF SPACE EXPOSURE OF SOME EPOXY MATRIX COMPOSITES ON THEIR THERMAL EXPANSION AND MECHANICAL PROPERTIES - G. Soulat, S.A. Matra, and Dr. Francois J. Changeart, CNES, France.

THE EFFECT OF THE SPACE ENVIRONMENT ON COMPOSITE MATERIALS - Michel Parcelier, Aerospatiale, France, and Dr. Francois J. Changeart, CNES, France.

MICROWELDING OF VARIOUS METALLIC MATERIALS UNDER ULTRAVACUUM - Jean Pierre Assie, Aerospatiale, France, and Dr. Francois J. Changeart, CNES, France.


THE EFFECT OF SPACE ENVIRONMENT EXPOSURE ON THE PROPERTIES OF POLYMER MATRIX COMPOSITE MATERIALS - Dr. R.C. Tennyson and Jorn S. Hansen, University of Toronto.

SPACE ENVIRONMENT EFFECTS ON SPACECRAFT MATERIALS - Dr. Michael J. Meshishnek, The Aerospace Corporation.

BALLOON MATERIALS DEGRADATION - David H. Allen and Dr. Thomas W. Strganac, NASA Langley Research Center.

THERMAL CONTROL COATINGS EXPERIMENT - A. Paillous, CERT/ONERA-DERTS, France, and Dr. Francois J. Changeart, CNES, France.

EXPOSURE OF SPACECRAFT COATINGS - Wayne S. Slemp, NASA Langley Research Center.

ION-BEAM-TEXTURED AND COATED SURFACES EXPERIMENT - Michael J. Mirtich Jr. and Bruce A. Banks, NASA Lewis Research Center.


LOW-TEMPERATURE HEAT PIPE EXPERIMENT PACKAGE - Roy McIntosh Jr., NASA Goddard Space Flight Center.


LDEF THERMAL MEASUREMENTS SYSTEM - William M. Berrios, NASA Langley Research Center.

Power and Propulsion

SPACE PLASMA HIGH-VOLTAGE DRAINAGE EXPERIMENT - Dr. William W.L. Taylor and Denise P. Traver, TRW Space and Technology Group.

SOLAR-ARRAY-MATERIALS PASSIVE LDEF EXPERIMENT - Ann F. Whitaker, Sally A. Little and Leighton E. Young, NASA Marshall Space Flight Center; Dr. David J. Brinker, NASA Lewis Research Center; James A. Bass, NASA Goddard Space Flight Center; and Paul M. Stella, Jet Propulsion Laboratory.

ADVANCED PHOTOVOLTAIC EXPERIMENT - Dr. David J. Brinker, NASA Lewis Research Center.

INVESTIGATION OF CRITICAL SURFACE DEGRADATION EFFECTS ON COATINGS AND SOLAR CELLS DEVELOPED IN GERMANY - Dr. Ludwig Preuss, Messerschmitt-Bolkow-Blohm Space Division, Federal Republic of Germany.

SPACE AGING OF SOLID ROCKET MATERIALS - Dr. Leon L. Jones and Oliver T. Chen, Morton-Thiokol, Inc.

Science

INTERSTELLAR-GAS EXPERIMENT - Dr. Don L. Lind, Utah State University, and Johannes Geiss and Joseph Fischer, University of Bern, Switzerland.

A HIGH-RESOLUTION STUDY OF ULTRAHEAVY COSMIC-RAY NUCLEI - Dr. Denis O'Sullivan and Dr. Alex Thompson, Dublin Institute for Advanced Studies, Ireland; and Vicente Domingo and Klaus-Peter Wenzel, European Space Agency, ESTEC, Noordwijk, The Netherlands.

HEAVY IONS IN SPACE - Dr. James H. Adams Jr., Rein Silberberg and C.H. Tsao, Naval Research Laboratory.

TRAPPED-PROTON ENERGY SPECTRUM DETERMINATION - Robb Fredrickson and Irving Michael, Air Force Geophysics Laboratory; Gerald J. Fishman, NASA Marshall Space Flight Center; Paul L. Segalyn, Army Materials and Mechanics Research Center; Peter J. McNulty, Clemson University; Y.V. Rao, Emmanuel College; and Christopher E. Laird, Eastern Kentucky University.
MEASUREMENT OF HEAVY COSMIC-RAY NUCLEI ON LDEF - Dr. Rudolf Beaujean, Wolfgang Enge and Georg Siegmon, University of Kiel, Federal Republic of Germany.

LINEAR ENERGY TRANSFER SPECTRUM MEASUREMENT EXPERIMENT - Dr. Eugene V. Benton, University of San Francisco, and Thomas A. Parnell, NASA Marshall Space Flight Center.

MULTIPLE-FOIL MICROABRASION PACKAGE - J.A.M. McDonnell, T.J. Stevenson and K. Sullivan, University of Kent at Canterbury, United Kingdom.

STUDY OF METEOROID IMPACT CRATERS ON VARIOUS MATERIALS - J-C. Mandeville, CERT/ONERA-DERTS, France, and Dr. Francois J. Changeart, CNES, France.

ATTEMPT AT DUST DEBRIS COLLECTION WITH STACKED DETECTORS - J-C. Mandeville, CERT/ONERA-DERTS, France, and Dr. Francois J. Changeart, CNES, France.

THE CHEMISTRY OF MICROMETEOROIDS - Dr. Friedrich Horz, David S. McKay and Donald A. Morrison, NASA Johnson Space Center; Donald E. Brownlee, University of Washington; and Robert M. Housley, Rockwell International Science Center.

CHEMICAL AND ISOTOPIC MEASUREMENTS OF MICROMETEOROIDS BY SECONDARY ION MASS SPECTROMETRY - Dr. Ernst K. Zinner, Robert M. Walker, Conel Alexander, John H. Foote and Patrick D. Swan, McDonnell Center for the Space Sciences, Washington University; Friedrich Horz, NASA Johnson Space Center; Hugo Fechtig and Elmar Jessberger, Max-Planck Institute for Nuclear Physics, Federal Republic of Germany; Eduard B. Igenbergs, Uwe Kreitmayr and Heribert Kuczera, Munich Technical University, Federal Republic of Germany; Eberhard Schneider, Ernst-Mach Institute, Federal Republic of Germany; and Norbert Pailer, Dornier System Manufacturing Co., Federal Republic of Germany.

INTERPLANETARY DUST EXPERIMENT - Dr. S. Fred Singer, Arlington; Philip C. Kassel Jr., NASA Langley Research Center; and Jim J. Wortman, North Carolina State University.

SPACE DEBRIS IMPACT EXPERIMENT - Donald H. Humes and Ronald A. Outlaw, NASA Langley Research Center.

FREE-FLYER BIOSTACK EXPERIMENT - Professor Horst Bucker and Professor Guenther Reitz, DFVLR, Institut Fur Flugmedizin, Federal Republic of Germany.

SEEDS IN SPACE EXPERIMENT - William John Park and Dr. Jim A. Alston, George W. Park Seed Company, Inc.

SPACE EXPOSED EXPERIMENT DEVELOPED FOR STUDENTS (SEEDS) - Larry Bilbrough and Dr. J. Gregory Marlins, NASA Headquarters.

Electronics and Optics

HOLOGRAPHIC DATA STORAGE CRYSTALS FOR LDEF - Dr. W. Russell Callen and Thomas K. Gaylord, Georgia Institute of Technology.

EXPOSURE TO SPACE RADIATION OF HIGH-PERFORMANCE INFRARED MULTILAYER FILTERS AND MATERIALS TECHNOLOGY EXPERIMENTS - Dr. John S. Seeley, University of Alabama; Roger Hunneman and A. Whatley, University of Reading, United Kingdom; and Derek R. Lipscombe, British Aerospace Corporation, United Kingdom.
EFFECT OF SPACE EXPOSURE ON PYROELECTRIC INFRARED DETECTORS - Dr. James B. Robertson and Ivan O. Clark, NASA Langley Research Center.

THIN METAL FILM AND MULTILAYERS EXPERIMENT - J.M. Berset, CNRS/LPSP, and Dr. Francois J. Changeart, CNES, France.

VACUUM-DEPOSITED OPTICAL COATINGS EXPERIMENT - Dr. Francois J. Changeart, CNES, France.

RULED AND HOLOGRAPHIC GRATINGS EXPERIMENT - Gilbert Moreau, Instruments S.A., Longjumeau, France, and Dr. Francois Changeart, CNES, France.

OPTICAL FIBERS AND COMPONENTS EXPERIMENT - J. Bourrieau, CERT/ONERA-DERTS, France, and Dr. Francois Changeart, CNES, France.

PASSIVE EXPOSURE OF EARTH RADIATION BUDGET EXPERIMENT COMPONENTS - John R. Hickey and Francis J. Griffin, The Eppley Laboratory Inc.

EFFECTS OF SOLAR RADIATION ON GLASSES - Ronald L. Nichols, NASA Marshall Space Flight Center, and Donald L. Kinser, Vanderbilt University.

STUDY OF FACTORS DETERMINING THE RADIATION SENSITIVITY OF QUARTZ CRYSTAL OSCILLATORS - Dr. John D. Venables and John S. Ahearn, Martin Marietta Laboratories.

INVESTIGATION OF THE EFFECTS OF LONG-DURATION EXPOSURE ON ACTIVE OPTICAL SYSTEM COMPONENTS - Dr. M. Donald Blue, James J. Gallagher and R.G. Shackelford, Georgia Institute of Technology.

INVESTIGATION OF THE EFFECTS OF LONG-DURATION EXPOSURE ON ACTIVE OPTICAL MATERIALS AND UV DETECTORS - Gale A. Harvey, NASA Langley Research Center.

FIBER OPTIC DATA TRANSMISSION EXPERIMENT - Dr. Alan R. Johnston and Larry A. Bergman, Jet Propulsion Laboratory.

SPACE ENVIRONMENT EFFECTS ON FIBER OPTICS SYSTEM - Edward W. Taylor, Air Force Weapons Laboratory.

SPACE ENVIRONMENT EFFECTS - TSgt. Mike Steskal, Air Force Technical Applications Center; Rodger Paquin, Perkin-Elmer; Richard C. Madonna, Grumman Aerospace Corp.; Robert R. Alfano, The City College, New York City; Andrew Schuerger, EPCOT Center; and Joseph A. Angelo Jr., EG&G Inc.