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SPACE EXPLORATION: SCIENTIFIC AND TECHNOLOGICAL ASPECTS

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Introduction

Roughly thirty years after first venturing beyond the confines of Earth, mankind has almost completed the initial reconnaissance of the solar system. Only Pluto remains unvisited by spacecraft, and plans exist to add that most distant outpost of the unknown to our list of space achievements. But much has changed since the heady days of the 1960's, when a United States commitment to "land a man on the Moon and return him safely to Earth by the end of the decade" led to a focusing of national resources on solar system exploration. Today, federal budget deficits and competing priorities dominate the US national agenda. Another great contributor to solar system exploration, the Soviet Union, has ceased to exist. Russia, beset with its own economic problems, is struggling to keep the former Soviet program on track. Germany, long an important contributor to space and solar system projects, is scaling back its efforts to meet the economic demands of unification.

In this environment of constrained resources, new approaches must be found to continue this bold endeavor. Two organizations within NASA, the Office of Exploration (OEXP) and the Solar System Exploration Division (SSED) of the Office of Space Science and Applications (OSSA), are advancing innovative, lower cost methods of exploring the Moon and planets. For the Moon and Mars, the focus of President Bush's renewed commitment to human and robotic exploration, the OEXP and the SSED are developing small spacecraft that will pave the way for eventual human presence while greatly advancing scientific understanding. For the rest of the solar system, NASA's SSED is extending the small spacecraft approach to comets, asteroids, and even distant Pluto. When brought to fruition, these programs promise to continue our great voyages of exploration in a manner consistent with the more modest budget expectations of the coming decade.

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Throughout our solar system voyages, issues have arisen which draw in the legal community. The launch of nuclear materials, the protection of other planets from terrestrial contamination and the Earth from "back" contamination, and the forging of international cooperative agreements are just a few of the areas in which the legal community has been engaged.

The purpose of this paper is to summarize NASA's current plans for solar system exploration, focusing on the robotic missions planned for the next decade, and to call attention to the legal issues which these missions are expected to raise.

Small Spacecraft and Solar System Exploration

Some of the most recent solar system exploration missions have been undertaken with spacecraft capable of a wide range of scientific investigations. Voyager, Galileo, and the planned Cassini mission to Saturn, for example, were designed to study the atmospheres, satellites, and magnetospheres[1] of outer solar system planets. Their payloads include diverse instruments ranging from cameras to spectrometers to magnetometers to plasma measurement instruments, and in the case of Galileo and Cassini, probes which will enter the atmospheres of Jupiter and Titan[2], respectively.

In order to accomplish these diverse objectives, these spacecraft are relatively large. Both Galileo and Voyager weighed about 2000kg (4400lb) at launch, roughly equally divided between spacecraft and fuel. Cassini is roughly twice as heavy.

In contrast, NASA is currently studying a mission to Pluto using a spacecraft weighing about 160kg (350lb), and a network of 60-kg (130-lb) Mars landers, each carried on a spacecraft weighing a total of about 250kg (550lb). Since spacecraft of this size carry more limited payloads, the key to missions of this nature is focused science objectives. These missions cannot address the broad range of questions of a Galileo or Cassini, but they can greatly advance our knowledge in specific areas.

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[1] A planet's magnetosphere is the region of space surrounding a planet in which the motion of charged particles is controlled by the planet's magnetic field.

[2] The largest moon of Saturn, whose surface is completely shrouded by an atmospheric haze.

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A particular type of small spacecraft mission is embodied in the Discovery Program, under development by NASA's SSED. These small missions will cost less than $150 million to develop, will take three years or less to develop, and will utilize a launcher no larger than a Delta II. Discovery is intended to increase the flight rate of planetary missions, provide for a more continuous stream of data, and encourage broad involvement in the planetary program.

The remainder of this section summarizes current NASA mission planning, with particular focus on the use of small spacecraft approaches and technologies.

Mars

Although Mars has long been an object of public fascination, it was only with the coming of the space age that we learned the compelling nature of Mars as an object of scientific study and a target for human explorers. Mars' compelling nature has much to do with its geologic and climatologic history. Extensive dendritic channels in the ancient Martian highlands indicate that flowing water, and perhaps rain, existed early in Mars' lifetime. During this same period, the first billion years after solar system formation, life began on Earth. If Mars was climatologically like Earth during this crucial period, did life form on Mars as well? And if not, why not? Either way, the answers to these questions hold profound importance for our understanding of how we came to inhabit Earth.

Today, of course, flowing surface water is impossible on Mars. Low temperatures and a thin atmosphere make Mars an arid desert, unsuitable to support life except perhaps in habitats protected from the harsh surface conditions. What caused the great global climate change from the warmer, wetter past we infer? Are there lessons in that change that may enhance our understanding of terrestrial climate change?

The Mariner 9 and Viking missions of the 1970's revealed Mars as a planet and enabled us to pose these and other challenging questions. The next step in addressing these questions is the launch of Mars Observer, scheduled for late September 1992. This polar orbiter will provide global maps of mineralogic and elemental composition, seasonal measurements of atmospheric structure and circulation, and a limited set of high resolution surface images.

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Following this global survey, we plan to return to Mars' surface. A NASA mission called the Mars Environmental Survey (MESUR) Network will begin emplacing a network of small stations around Mars in 1999. By 2004, about 16 MESUR Network stations will be distributed around the globe, measuring Martian seismicity, meteorology, and surface chemistry. Each station will also be equipped with a panoramic camera and perhaps a small "microrover" to deploy scientific instruments and venture beyond the landers reach. Together, these measurements will help us understand Mars interior, its global atmospheric circulation, and its surface composition and geologic processes.

The MESUR Network landers will be launched in groups of four on a Delta II expendable launcher. Each 60-kg (130-lb) lander will be encased in an "aerocraft" that will fly independently to Mars and enter the atmosphere ballistically. A parachute will slow the lander in its descent to the surface. Four launches, one each in 1999 and 2001 and two in 2003, will be required to deliver the full complement of 16 landers. A communications orbiter will be used to relay data back to Earth.

Before committing to placing 16 MESUR Network landers on Mars, we plan to send one, called MESUR Pathfinder, as a test of the MESUR entry, descent, and landing systems. MESUR Pathfinder, to be launched in 1996, will also carry a modest science payload to begin our renewed surface exploration and help us design more effective MESUR investigations. MESUR Pathfinder will be flown as the first Discovery mission (see below).

The United States is not the only nation planning to send landers to Mars during this period. Russia plans to launch missions in 1994 and 1996. The Mars-94 mission will carry two small stations and two penetrators, the latter for sub-surface measurements. Mars-96 will add a balloon-borne payload and a rover to the complement of Russian spacecraft. Several European nations are participating in these missions through the provision of instruments, subsystems, and--in the case of France--the balloon system.

The European Space Agency (ESA) also plans to add elements to the surface network through its MarsNet program. Three or four landers would be designed to conduct a regional investigation on Mars while simultaneously contributing to the global network. These landers would be delivered to Mars by the US as part of a MESUR-MarsNet cooperative program.

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Planning beyond these missions is speculative at best, but NASA is studying the use of small spacecraft for returning samples from Mars. Such a spacecraft would deliver a Mars ascent vehicle (MAV) to the surface using an entry, descent, and landing system derived from MESUR. A small rover would collect samples and return them to the MAV, which would in turn bring them to an Earth return vehicle waiting in Mars orbit, or return them directly to Earth. The analysis and age-dating of these samples in terrestrial laboratories will provide otherwise inaccessible insights into the formation and evolution of Mars, as well as the safety and suitability of Mars for eventual human presence.

The Moon

Unlike Mars, the Moon is a planet frozen in geologic time. Its ancient cratered highlands record an intense bombardment during the first half billion years of solar system history. For the next billion years, ending about 3 billion years ago, lunar volcanism formed vast lava plains which we call mare. But since the end of mare formation, the Moon's surface has been altered mainly by occasional impacts of small bodies which encounter the Earth-moon system.

Whereas Mars provides a chronicle of planetary evolution, the Moon provides a Rosetta stone of planetary formation and the role of impacts. The Moon may have been formed as the result of the greatest impact ever to affect the Earth--a collision with a Mars-sized body during planetary formation. If so, the Moon may hold clues to the earliest epoch in Earth's history. The Moon may hold clues as well to the role of impacts in biological evolution on Earth. Global catastrophes from impacts by bodies about 10km in diameter are now thought to have caused many of the great extinctions recorded in the fossil record, including that of the dinosaurs 65 million years ago. The Moon's surface, unaffected by the weather and plate tectonics which erase craters on Earth, preserves a unique record of the more recent impact environment of the Earth-moon system. Suggestions of periodic extinction-causing impacts could be tested by careful sampling and study of lunar craters.

The moon provides another unique history as well, that of the ancient sun. Solar wind and solar flares particles implanted in the lunar surface soil and rocks were detected in the Apollo samples. Materials once exposed on the surface and then buried by impacts or

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lava flows could provide snapshots of the ancient sun, helping us understand the role of solar variability in climatic change on Earth.

Current NASA planning for lunar robotic missions is focused on orbital and landed missions planned by the Office of Exploration (OEXP) as precursors to human return to the Moon. The first elements of this plan are two orbiters, called Lunar Scouts, which would address key scientific objectives while providing engineering information and resource characterization important for future human exploration. Both orbiters are relatively small, about 1000kg (2200lb). The first would carry instruments to measure surface elemental composition and to detect and characterize near-surface water, and a high-resolution stereo mapping camera to obtain a global image database. The second would carry a complementary elemental composition instrument and a spectrometer to map mineral distributions. Together, both spacecraft would determine the full lunar gravitational field, important information both for an understanding of the lunar interior and for future mission design.

The Lunar Scouts would be followed by landers of the Artemis Program. Artemis would allow intensive surface investigation and certification for human landing of sites identified from the global Lunar Scout data. Potential Artemis payloads would include rovers, resource utilization experiments, and telescopes (which would take advantage of the Moon's airless surface).

Pluto

Pluto, the last unexplored planet in the solar system, is the most distant from the sun, and the most difficult to reach by spacecraft. For that reason it has heretofore been an "astronomer's planet," the object only of gazing from afar. Until 1976, astronomers had discovered little other than Pluto's existence (the result of a search for a more massive object--which we now know does not exist--that appeared to be perturbing the orbits of Uranus and Neptune) and its orbital and rotational characteristics. The late 1970's, however, saw two major discoveries: the presence of frozen methane on Pluto's surface and the existence of Pluto's satellite Charon. Since then, observations of Pluto and Charon passing in front of one another

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have yielded crude "maps" of the surfaces of both, and additional information about the Pluto-Charon system.[3]

Interest in Pluto was stimulated by the 1989 flyby of Neptune by the Voyager 2 spacecraft. On Neptune's moon Triton, a body similar to Pluto in size and general characteristics, Voyager discovered active geysers, possibly driven by the vaporization of solar-heated nitrogen ice a few meters below Triton's surface. Add to this Voyager images showing vast frozen lakes that may have resulted from ancient eruptions of ammonia-laden water, and we now have a picture of an amazingly active Triton that belies its earlier image as a distant, frozen body. Given Voyager's discoveries at Triton, what might we discover with the first spacecraft reconnaissance of Pluto? The one thing that would be surprising was if we were not surprised.

Travel to Pluto is difficult. An earlier-studied mission that would have sent to Pluto a large spacecraft similar to that used for the Cassini Saturn mission would have required a 14-year flight-time. The flight-time would have been that short only because Jupiter would have been used as a gravitational slingshot to accelerate the spacecraft toward its distant destination.

The Pluto mission NASA is studying today, in contrast, uses a spacecraft weighing less than 150kg. It cannot carry the broad suite of instruments a Cassini-class spacecraft could, but it appears possible to carry a key set of 3-4 instruments that would allow characterization of Pluto's geology, surface composition, and neutral atmosphere. The spacecraft would fly directly to Pluto in 7-10 years, the exact flight-time depending on the spacecraft mass and the type of launcher used. Freed from the necessity of getting a gravity assist from Jupiter, it could be launched any year, rather than having to wait for the once-every-thirteen-year Jupiter opportunities.

The Discovery Program

Rounding out NASA's small spacecraft approach to solar system exploration is Discovery, a program of low-cost (less than $150 million dollars) missions intended to improve the planetary mission flight rate, provide a more continuous stream of planetary data, and broaden the public, academic, and industrial participation in solar

[3] An excellent review entitled *The Pluto-Charon System* has recently been published by S.A. Stern, The Annual Review of Astronomy and Astrophysics 30, 185-233 (1992).

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system exploration. From 1979 to the present, just three U.S. planetary missions have been launched: Magellan to Venus and Galileo to Jupiter in 1989, and Mars Observer in 1992. The result has been an uneven "feast or famine" flow of planetary data into the scientific community and through it into society. The Discovery Program seeks an eventual launch rate of a mission a year or better, beginning with two missions launched 14 months apart.

The first of these two is MESUR Pathfinder, the engineering test of the MESUR Network entry, descent, and landing system described above. MESUR Pathfinder would be launched to Mars in November 1996. The second Discovery mission, the Near-Earth Asteroid Rendezvous (NEAR), would be launched in January 1998 to meet the Earth-approaching asteroid Nereus two years later. Flying along side Nereus for about a year, the NEAR spacecraft would determine its bulk properties such as size, shape, volume, mass, gravitational field and spin rate, as well as measure composition and other surface properties. These detailed measurements would complement the recent flyby data returned by the Galileo spacecraft for the main-belt asteroid Gaspra, and begin our spacecraft investigation of the vitally important Earth-approaching objects.

Discovery missions following NEAR were the subject of a recent workshop held in San Juan Capistrano, California. Seventy-three concepts for future Discovery missions were presented at that workshop, illustrating the diversity of ideas in the academic, research, and industrial communities for small solar system missions. The concepts presented ranged from Mercury flybys and orbiters; to Venus landers, atmospheric probes, and orbiters; to lunar orbiters and landers; to comet and asteroid flyby and rendezvous missions; to Mars landers and orbiters; and even to missions to the outer solar system. NASA will be studying some of these missions as part of its continuing development of the Discovery Program.

Legal Issues

The intent here is not to discuss legal issues in any depth, but to briefly note some areas in which the missions discussed here engage the legal community.

Planetary Protection

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Article IX of the 1967 Outer Space Treaty commits the signers, which include all the major space-faring nations, to

> "pursue studies of outer space, including the moon and other celestial bodies, and conduct exploration of them so as to avoid their harmful contamination and also adverse changes in the environment of the Earth resulting from the introduction of extraterrestrial matter..."

The term "planetary protection" has come to signify activities that support this clause. Practically speaking, planetary protection refers to protection against biological contamination, both the contamination of extraterrestrial bodies by terrestrial organisms (forward contamination), and the contamination of Earth's environment by extraterrestrial organisms. At present, only biological contamination presents the hazard of inadvertent, widespread planetary contamination, but only under limited circumstances. Our desire to preserve planetary surfaces for future study has dictated a careful exploration strategy, adapting our planetary protection procedures to our emerging knowledge of planetary environments and their ability to support life.

The issues become increasingly severe as we progress from flyby, to orbital, to landed, to sample return missions. In flyby and orbital missions, the principal issue is assuring that the spacecraft does not contaminate the planet through unintended atmospheric entry. For landed missions, consideration must be given to the introduction of terrestrial microbes into the planetary environment. Sample return missions must address as well any potential hazards posed by the return of extraterrestrial materials or life forms.

Addressing planetary protection requirements can have a significant impact on mission cost and design. An orbital mission may have to carry extra fuel to boost it to a quarantine orbit following its nominal mission. A landed mission may have to be heat or chemically treated to reduce its bioload. (The Viking mission to Mars was heat treated not only to satisfy planetary protection requirements, but also to insure that terrestrial microbes did not produce positive results in the Viking life detection experiments.) Sample return missions may have to go through elaborate procedures to insure that the returned materials pose no hazard to the Earth's environment. The definition of planetary protection requirements is thus of great concern to mission designers and space agencies.

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The monitoring body for planetary protection requirements is the Committee on Space Research (COSPAR). At its biannual meeting, COSPAR provides a forum for discussion of the broad range of planetary protection issues, and a mechanism for formulating policy to address emerging issues. Recently, the Space Studies Board of the National Research Council issued the results of a study of the biological contamination of Mars.[4] Given the focus on Mars in both the U.S. and Russian space programs, this area should be a major topic of discussion at the 1994 COSPAR meeting in Hamburg.

Launch and Use in Space of Nuclear Materials

Planetary missions sometimes carry systems containing radioactive materials. The principal use of radioactive materials on planetary spacecraft is energy, either heat or electrical. Heat is sometimes provided by a radioisotope heat unit (RHU) containing a small amount of plutonium 238. Electricity, particularly for outer solar system missions which cannot rely on abundant sunlight, is often provided by radioisotope thermoelectric generators, also powered by plutonium 238.

The National Environmental Policy Act (NEPA) of 1969, as amended, requires that NASA (and all other Federal agencies) prepare an Environmental Impact Statement (EIS) before taking any actions that may affect the environment. NEPA was extended in 1979 by Executive Order 12114 on "Environmental Effects Abroad of Major Federal Actions." Although the risk of accidental release of nuclear material during a space mission is very slight, an EIS is nonetheless required for every NASA mission that involves such material. It is important to note that the purpose of the EIS is "to ensure that environmental information is available [to the public] before decisions are made and before actions are taken." The NEPA process does not preclude Federal agencies from taking actions that might impact the environment.

In 1977, President Carter issued a Presidential Directive (PD/NSC-25) on "Scientific or Technological Experiments with Possible Large-Scale Adverse Environmental Effects and Launch of Nuclear Systems into Space." That Directive provided that

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[4] *Biological Contamination of Mars: Issues and Recommendations,* National Academy Press, Washington, D.C., 1992.

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- Where such experiments constitute [a major Federal action] that significantly affect the quality of the human environment, an environmental impact statement [EIS] will be prepared..."

- "...a nuclear safety evaluation report [SER] ... is required for launches of spacecraft utilizing [major] radioactive sources ..."

- "An ad hoc Interagency Nuclear safety Review Panel [INSRP] consisting of members from the [DOD, DOE, and NASA] will evaluate the risks associated with the mission and prepare a [SER]."

- The head of the sponsoring agency will request the President's approval for the flight through the Office of Science and Technology Policy [OSTP]. The [OSTP] Director is authorized to render approval for such launchings ..."

Major legal actions preceded the launches of the two most recent NASA missions carrying RTG's: the Galileo mission to Jupiter, launched in 1989, and the Ulysses mission to study the polar regions of the sun, launched in 1990. We may expect that legal action will continue to be associated with the launch of nuclear materials.

The use of nuclear materials in space is also a subject of international dialogue. A set of "Draft Principles Relevant to the Use of Nuclear Power Sources in Outer Space" was adopted by consensus by the United Nations Special Political Committee on October 30, 1992. These Principles apply to the use of nuclear power sources excluding nuclear propulsion systems.

Dr. D. Allan Bromley, head of the White House Office of Science and Technology Policy and the President's executive agent under PD/NSC-25, advised in a letter to the U.S. Secretaries of Defense and Energy and the NASA Administrator that the U.N. Principles do not yet contain the clarity and sound technical standards necessary to serve as a basis for decision making. He further stated, "As our delegation made clear, pending necessary technical revisions, the U.S. Government will not look to these flawed Principles as standards of review for space launches involving nuclear power sources." The U.S. plans to

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work with U.N. members to revise the Principles to properly address all future use of nuclear material in space.

Possession by "Telepresence"

"Telepresence," the ability to make it appear to a human that he or she is in a remote location, is of extreme interest to the planetary research community. A researcher sitting in a laboratory on Earth could, for example, explore the surface of the Moon by means of a robot which provided mobility, multi-spectral vision, tactile sensation, etc. Similarly, an astronaut in a Martian base could explore remote regions of the planet without leaving the safety of her planetary habitat.

Telepresence recently entered the legal arena in a case involving the SS Central America, a ship that sank in a storm off the southeast coast of the United States in 1857 carrying a cargo of gold coin and bullion from San Francisco. That cargo, valued at $2 billion today, was the subject of a US District Court action. An injunction was granted to the discoverers of the wreck, enjoining others from salvage. The discoverers' possession of the wreck was based on remote, robotic examination and retrieval of artifacts, which for this purpose was defined as telepresence.[5]

Although telepresence is unlikely to become a major concern of space law in the foreseeable future, the SS Central America case illustrates how technologies in use both on Earth and in space can open up new legal issues and challenge our jurisprudence.

Acknowledgments

The work described here is not the author's, but that of hundreds of scientists and engineers who it is not practical to thank individually. I thank John Appleby, John Rummel, William Smith, Douglas Stetson, and Howard Wright for valuable reviews and revisions of the manuscript.

[5]See *"Telepossession is 9/10 of the Law: The Emerging industry of Deep Ocean Discovery,* Pace Yearbook of International Law, v.3, 309-362 (1991).

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SPACE EXPLORATION: SCIENTIFIC AND TECHNOLOGICAL ASPECTS

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On July 20, 1989, President Bush declared U.S. space goals of returning humans to the Moon--this time to stay--and then sending humans to Mars. Dubbed "Mission From Planet Earth" by the Augustine Presidential Advisory Committee, this program will require technological and scientific developments in many areas. Among these areas are life support and health maintenance, space radiation characterization and protection, launch and space transfer vehicles, and planetary environmental characterization. Some of these needs, particularly planetary characterization, will be addressed by robotic missions which will precede human landings. Robotic missions will also be used to continue the scientific exploration of the Moon, Mars, and other solar system bodies begun in the 1960's. These programs of exploration raise numerous legal issues, for example, a treaty-level commitment to avoid contaminating other planets or introducing harmful extraterrestrial matter into the terrestrial environment. These interrelated technological, scientific, and legal issues will be discussed.

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NASA

BROAD POLICY FOR SEI

- National Space Policy
  - states specific goal of expanding human presence and activity beyond Earth orbit into the solar system
- Speech of July 20, 1989 by President Bush
  - provides the charter for SEI: first Space Station Freedom, then back to the Moon to stay, and then a manned mission to Mars
- February 21, 1990 White House policy decision on SEI
  - early SEI program will focus on technology development and innovative approaches, and take several years defining two or more architectures, concurrently performing mission studies
- White House statement of March 30, 1990
  - U.S. will seek an exploratory dialogue on possible international cooperation

Together these Presidential statements provide a core body of policy for SEI

Office of Aeronautics, Exploration and Technology

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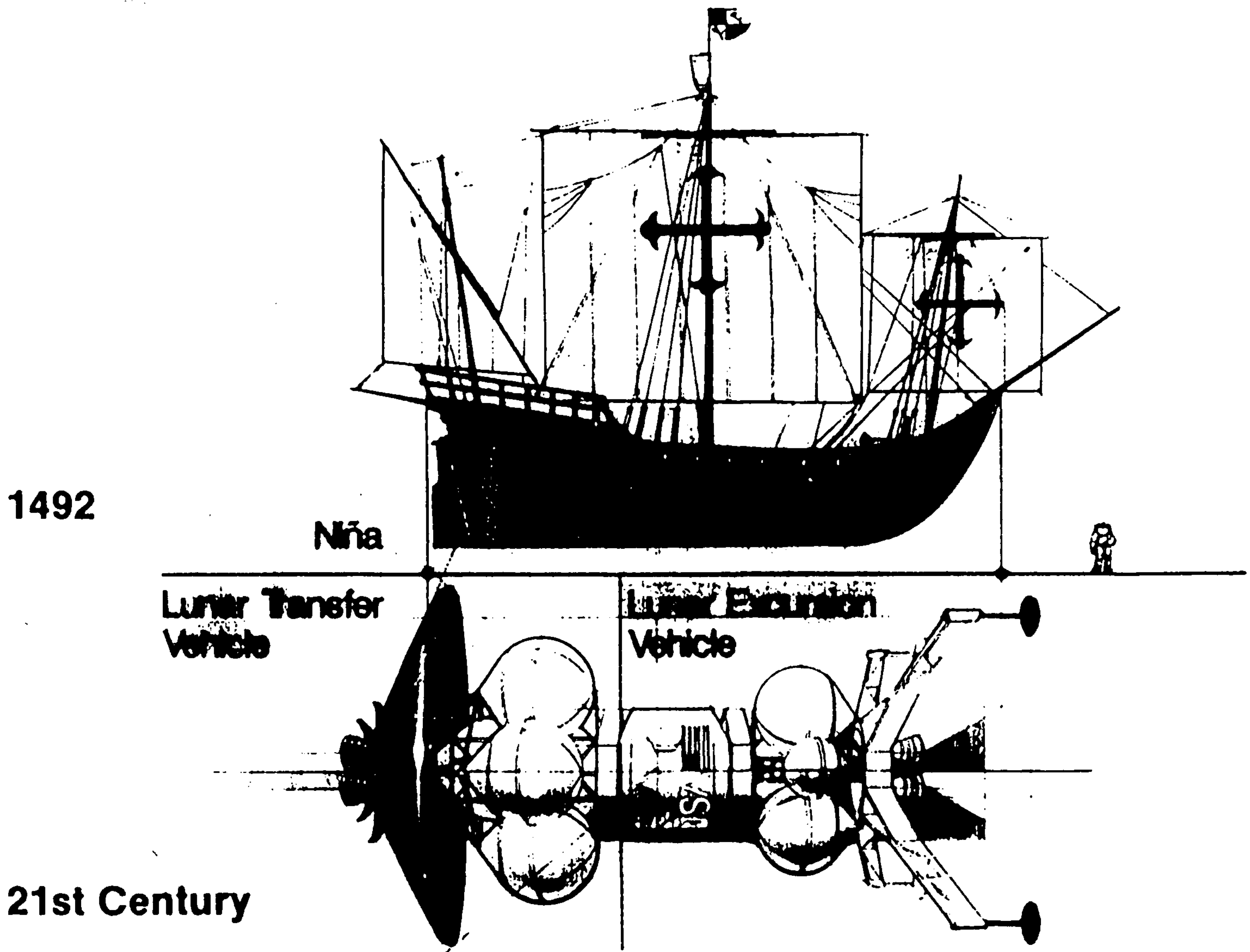
Ships of Exploration



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NASA

ARTIFICIAL GRAVITY?

Microgravity exposure causes major physiological change

- Bone mineral loss
- Muscle atrophy
- Cardiac deconditioning

Current countermeasures (exercise) may be insufficient for the lengthy voyage to Mars

Strategy to test and evaluate necessary zero-g countermeasures will utilize

- Soviet long duration experience
- Space Shuttle extended duration orbiter
- Space Station Freedom and eventually
- The lunar outpost itself

Current approach: plan a zero-g Mars transfer vehicle, but begin low level definition of an artificial gravity system just in case

Humans must be certified for journey to Mars

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Barrios3/OEXP Top 20-2 4/27/90

Ver. 2/1-30-90

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RADIATION PROTECTION

HAZARDS

- o Solar Flares
  - Can be lethal
  - Not currently predictable

- o Galactic Cosmic Rays (GCR)
  - Large uncertainties in biological effects
  - Unacceptable worst-case shielding requirements

RADIATION HEALTH PROGRAM

- o Radiation Characterization
  - Characterize GCR flux (mass, energy, time)
  - Develop solar flare monitors and prediction capability

- o Radiation Biology
  - Reduce uncertainty in GCR effects through ground-based program
  - Validate results in space (Lifesat)

- o Shielding Design

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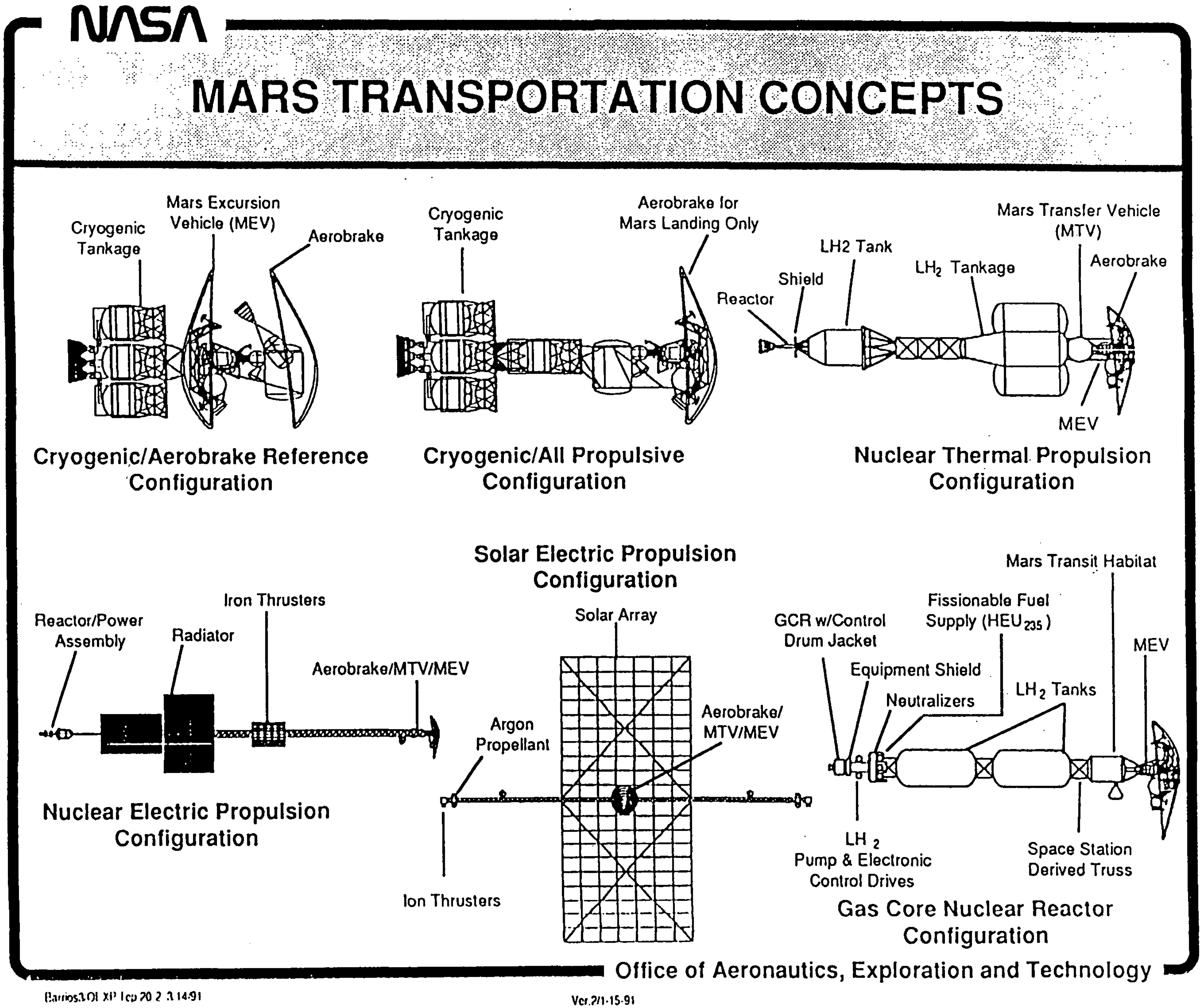

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NASA

EXPLORATION TECHNOLOGY PROGRAM

Space Transportation
- Aerobraking; spaced-based engines; and autonomous vehicle maneuvering

In-Space Operations
- Cryogenic fluid systems; in-space assembly and construction; and vehicle servicing and processing

Surface Operations
- Space nuclear power; in situ resource utilization; planetary rovers; surface solar power; and surface habitats and construction

Human Support
- Regenerative life support; radiation protection; extravehicular activity systems; and Exploration human factors

Lunar and Mars Science
- Sample acquisition, analysis and preservation; and planetary probes and penetrators

Information Systems and Automation
- High-rate communications; Exploration automation and robotics; and planetary photonics

Nuclear Propulsion
- Nuclear thermal propulsion; and nuclear electric propulsion

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Barrios3/OEXP Top 20-2 3/6/90

Ver. 1/3-5-90

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SCIENCE ON MARS

SEARCH FOR LIFE

- Warmer, wetter past
- Life may have started contemporaneously on Earth and Mars
- Life may exist today in protected underground environments
- Answers have profound implications

GLOBAL CLIMATE CHANGE

- Chronology, characteristics
- Role of geologic processes (e.g., volcanism, weathering)
- May enhance our understanding of climate change on Earth

GEOLOGIC DIVERSITY

- Complex planet shaped by many processes

- Tectonics	- Wind erosion
- Volcanism	- Flowing water

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SCIENCE ON THE MOON

LUNAR ORIGIN/EVOLUTION

- o Impact origin theory ----> common origin with Earth
- o Larger role for planetary scale collisions?

HISTORY OF THE SUN (PRESERVED IN LUNAR SOIL)

- o Solar wind trapped in regolith
- o Buried regolith provides time resolution

EXTINCTIONS CAUSED BY IMPACTS

- o Evidence in lunar cratering record?

UNPARALLELED RESOLUTION, SENSITIVITY FOR ASTRONOMY/ASTROPHYSICS

- o Large apertures
- o Interferometric arrays
- o Cosmic Ray Observatory

LIFE SCIENCE

- o Basic research: radiation environment, low gravity effects . . .
- o Supporting Mars exploration

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ROBOTIC MISSIONS

- Rich scientific returns from robotic exploration program begun in 1960's
- Viking last mission to Mars (1976 - 2 landers, 2 orbiters)
- Mars Observer (orbiter) to be launched in 1992

Objectives of future missions

- Continue advancing scientific understanding and developing basis for human exploration
- Identify suitable landing and outpost sites
- Provide design data for human mission elements
- Demonstrate technologies and operational concepts for human missions

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FUTURE ROBOTIC MISSIONS

Moon

- o Lunar Observer
  - Orbiting geochemical mapper

Mars

- o Mars Observer
  - Orbiting geochemical mapper and atmospheric sounder

- o Mars Network
  - Emplace planet-wide network of geophysical/meteorological monitoring stations
  - Conduct in situ geochemical analysis

- o Mars rovers and sample return
  - Conduct in situ investigations of surface
  - Return samples for detailed analysis

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THE OUTER SPACE TREATY

Entered into Force 10 October 1967

ARTICLE IX

States Parties to the Treaty shall pursue studies of outer space, including the moon and other celestial bodies, and conduct exploration of them so as to avoid their harmful contamination and also adverse changes in the environment of the Earth resulting from the introduction of extraterrestrial matter...

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SPACE SETTLEMENTS

PUBLIC LAW 100-685 NOV. 17, 1988
102 STAT. 4094-95

Sec. 217. (a) The Congress declares that the extension of human life beyond Earth's atmosphere, leading ultimately to the establishment of space settlements, will fulfill the purposes of advancing science, exploration, and development and will enhance the general welfare.

NASA directed to submit biannual report reviewing and analyzing:

- necessary research and technology
- alternative settlement locations and architectures
- mechanism for international cooperation
- economics of financing
- sociological factors (including legal issues)

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NASA

ANTARCTIC ANALOG

- NASA and NSF have a Memorandum of Agreement to collaborate on Antarctic activities applicable to space research and exploration
    - NASA envisions a planetary outpost prototype in Antarctica building on NSF experience
- The dry valleys, mountains and lakes of Antarctica provide the most Mars-like environment on Earth in terms of remoteness, terrain, temperature and historical ecology
- This "Antarctic Analog" will provide a unique and accessible test-bed for the development of Lunar and Mars systems:
    - Life support hardware
    - Science equipment and activities
    - Remote operations, automation and robotic, telepresence
    - Human behavior and performance

Test the systems in Antarctica first

Office of Aeronautics, Exploration and Technology

Barrios3 OEXP Top 20-3 3/14/91

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THE AUGUSTINE COMMITTEE

o Presidential Advisory Committee on Future of US Space Program chaired by Norman Augustine

o Recommendations
- Space science should be NASA's first priority

- Mission from Planet Earth (MFPE) be established with long-term goal of human exploration of Mars

- MFPE be tailored to match availability of funds ("go as you pay")

- Space Station Freedom be reconfigured to for only two missions: first, life sciences; second, microgravity research and applications

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NASA

WHY EXPLORE?

Scientific Knowledge

Technology Catalyst

Economic Stimulus

Human Spirit

National Pride

International Cooperation

Commercial Enterprise

Educational Improvement

International Prestige

U. S. Leadership

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NASA

REMARKS BY RICHARD DARMAN

DIRECTOR OF THE OFFICE OF MANAGEMENT AND BUDGET

"I can't think of any better [way to spend our nation's resources] than investment in space. That is the essence of the test of how much we care about the future. Because the benefit of investment in space will accrue primarily to the next generation. It's a fundamental moral test for society: whether it is willing to invest some of its own resources now for the benefit of those yet to come."

"...let's choose the future."

Face the Nation

July 23, 1989