Lunar Bases
and Space Activities of the 21st Century

W. W. MENDELL, EDITOR

Lunar and Planetary Institute
Houston
Lunar bases and space activities of the 21st century.

TL799.M6183 1985 919.9'104 86-50
ISBN 0-942862-02-3

Copyright 1985 by the Lunar and Planetary Institute.

This work relates to NASA Contract Nos. NASW-3389 and NAS-9-17023. The U.S. Government has a royalty-free license to exercise all rights under the copyright claimed herein for Government purposes. All other rights are reserved by the Lunar and Planetary Institute.

Published by the Lunar and Planetary Institute, 3303 NASA Road One, Houston, TX 77058-4399. Printed in the U.S.A. Library of Congress CIP data available from the Library of Congress, CIP Division, or from the publisher.

Cover illustration: Two inhabitants of the Moon overlook an advanced lunar installation from a museum construction site. The original, primitive lunar base lies to the left of a large electromagnetic launch facility, which dominates the vista. An array of solar dynamic generators on the horizon supplement the power from a nuclear reactor to operate greenhouses, industrial processing plants, scientific research laboratories, and a spaceport. Artist: Pat Rawlings, Eagle Engineering Co., Houston, Texas.
Associate Editors

Michael B. Duke
*NASA/Johnson Space Center*

Harold P. Klein
*University of Santa Clara*

Chris W. Knudsen
*Carbotek, Inc.*

John M. Logsdon
*George Washington University*

Wendell W. Mendell
*NASA/Johnson Space Center*

Barney Roberts
*NASA/Johnson Space Center*

Richard Tangum
*University of Texas*

Richard Williams
*NASA/Johnson Space Center*

David Vaniman
*Los Alamos National Laboratory*
CONTENTS

PROLOGUE 1

1 / THE SYMPOSIUM: KEYNOTE SPEECHES 5
Remarks on the Lunar Base  /  7
James M. Beggs
The Challenges and Opportunities of a New Era in Space: How Will We Respond?  /  11
G. A. Keyworth II
In Space: One World United  /  15
Walter J. Hickel
An Opportunity for Openness  /  21
Arthur Kantrowitz
Thoughts on a Lunar Base  /  25
Edward Teller

2 / LUNAR BASE CONCEPTS 33
Lunar Bases: A Post-Apollo Evaluation  /  35
Paul D. Lowman Jr.
Evolution of Concepts for Lunar Bases  /  47
Stewart W. Johnson and Ray S. Leonard
Strategies for a Permanent Lunar Base  /  57
Michael B. Duke, Wendell W. Mendell, and Barney B. Roberts
Preliminary Design of a Permanently Manned Lunar Surface Research Base  /  69
Stephen J. Hoffman and John C. Niehoff
Merits of A Lunar Polar Base Location  /  77
James D. Burke
Nuclear Energy—Key to Lunar Development  /  85
David Buden and Joseph A. Angelo Jr.
Nuclear Powerplants for Lunar Bases  /  99
J. R. French

3 / TRANSPORTATION ISSUES 109
Mission and Operations Modes for Lunar Basing  /  111
Gordon R. Woodcock
Impact of Lunar and Planetary Missions on the Space Station  /  125
A Moon Base/Mars Base Transportation Depot / 141
Paul W. Keaton

Achromatic Trajectories and the Industrial-Scale Transport of Lunar Resources / 155
T. A. Heppenheimer

A Lunar-Based Propulsion System / 169
Sanders D. Rosenberg

Launching Rockets and Small Satellites from the Lunar Surface / 177
K. A. Anderson, W. M. Dougherty, and D. H. Pankow

4 / LUNAR SCIENCE  187

The Need for a Lunar Base: Answering Basic Questions about Planetary Science / 189
G. Jeffrey Taylor

Geochemical and Petrological Sampling and Studies at the First Moon Base / 199
Larry A. Haskin, Randy L. Korotev, David J. Lindstrom, and Marilyn L. Lindstrom

A Closer Look at Lunar Volcanism from a Base on the Moon / 211
D. T. Vaniman, G. Heiken, and G. J. Taylor

Advanced Geologic Exploration Supported by a Lunar Base: A Traverse Across the
Imbrium-Prosceellarum Region of the Moon / 223
Mark J. Cintala, Paul D. Spudis, and B. Ray Hawke

Search for Volatiles and Geologic Activity from a Lunar Base / 239
Larry Jay Friesen

Unmanned Spaceflights Needed as Scientific Preparation for a Manned Lunar Base / 245
Don E. Wilhelms

The Next Generation Geophysical Investigation of the Moon / 253
L. L. Hood, C. P. Sonett, and C. T. Russell

Geophysics and Lunar Resources / 265
D. Strangway

Surface Electromagnetic Exploration Geophysics Applied to the Moon / 271
Mark E. Ander

5 / SCIENCE ON THE MOON  279

Astronomical Interferometry on the Moon / 281
Bernard F. Burke

A Moon-Earth Radio Interferometer / 293
Jack O. Burns

A Very Low Frequency Radio Astronomy Observatory on the Moon / 301
James N. Douglas and Harlan J. Smith

© Lunar and Planetary Institute • Provided by the NASA Astrophysics Data System
Lunar Based Gamma Ray Astronomy / 307
Robert C. Haymes

Irradiation of the Moon by Galactic Cosmic Rays and Other Particles / 315
James H. Adams Jr. and Maurice M. Shapiro

Celestial Sources of High-Energy Neutrinos as Viewed from a Lunar Observatory / 329
Maurice M. Shapiro and Rein Silberberg

A Lunar Neutrino Detector / 335
M. Cherry and K. Lande

Neutrino Measurements on the Moon / 345
Albert G. Petschek

Mass Extinctions and Cosmic Collisions: A Lunar Test / 349
Friedrich Hörz

6 / LUNAR CONSTRUCTION 361

Lunar Base Design / 363
Peter Land

A Surface-Assembled Superstructure Envelope System to Support Regolith Mass-Shielding for an Initial-Operational-Capability Lunar Base / 375
Jan Kaplicky and David Nixon

Concrete for Lunar Base Construction / 381
T. D. Lin

Concrete and Other Cement-Based Composites for Lunar Base Construction / 391
J. Francis Young

Magma, Ceramic, and Fused Adobe Structures Generated In-Situ / 399
E. Nader Khalili

Lava Tubes: Potential Shelters for Habitats / 405
Friedrich Hörz

Design of Lunar-Based Facilities: The Challenge of a Lunar Observatory / 413
Stewart W. Johnson and Ray S. Leonard

Environmental Considerations and Waste Planning on the Lunar Surface / 423
Randall Briggs and Albert Sacco Jr.

7 / LUNAR MATERIALS AND PROCESSES 433

Toward a Spartan Scenario for Use of Lunar Materials / 435
Larry A. Haskin

Mining for Lunar Base Support / 445
E. R. Podnieks and W. W. Roepke
Electrostatic Concentration of Lunar Soil Minerals / 453
William N. Agosto

In Situ Rock Melting Applied to Lunar Base Construction and for Exploration Drilling and Coring on the Moon / 465
John C. Rowley and Joseph W. Neudecker

Microwave Processing of Lunar Materials: Potential Applications / 479
Thomas T. Meek, David T. Vaniman, Franklin H. Cocks, and Robin A. Wright

James D. Blacic

Guide to Using Lunar Soil and Simulants for Experimentation / 497
J. H. Allton, C. Galindo Jr., and L. A. Watts

Fractional Distillation in a Lunar Environment / 507
Donald R. Pettit

Lunar Machining / 519
William Lewis

8 / OXYGEN: PRELUDE TO LUNAR INDUSTRIALIZATION / 529

A Parametric Analysis of Lunar Oxygen Production / 531
Michael C. Simon

Lunar Oxygen Production from Ilmenite / 543
Michael A. Gibson and Christian W. Knudsen

Oxygen Extraction from Lunar Materials: An Experimental Test of an Ilmenite Reduction Process / 551
Richard J. Williams

A Carbothermal Scheme for Lunar Oxygen Production / 559
Andrew Hall Cutler and Peter Krag

Lunar Regolith Fines: A Source of Hydrogen / 571
James L. Carter

Hydrogen Recovery From Extraterrestrial Materials Using Microwave Energy / 583

Microbial Extraction of Hydrogen from Lunar Dust / 591
David C. White and Peter Hirsch

Hydrogen and Water Desorption on the Moon: Approximate On-Line Simulations / 603
G. E. Blanford, P. Børjesen, M. Maurette, W. Möller, and B. Monart

An Analysis of Alternate Hydrogen Sources for Lunar Manufacture / 611
Herbert N. Friedlander
9 / LIFE SUPPORT AND HEALTH MAINTENANCE 621

The Evolution of CELSS for Lunar Bases  / 623
R. D. MacElroy, Harold P. Klein, and M. M. Averner

Wheat Farming in a Lunar Base  / 635
Frank B. Salisbury and Bruce G. Bugbee

Metabolic Support for a Lunar Base  / 647
R. L. Sauer

Implementing Supercritical Water Oxidation Technology in a Lunar Base Environmental Control/Life Support System  / 653
Melaine Meyer Sedej

Radiation Transport of Cosmic Ray Nuclei in Lunar Material and Radiation Doses  / 663
R. Silberberg, C. H. Tsao, J. H. Adams Jr., and John R. Letaw

Aerosol Deposition Along the Respiratory Tract at Zero Gravity: A Theoretical Study  / 671
B. E. Lehner, D. M. Smith, L. M. Holland, M. I. Tillery, and R. G. Thomas

Toward the Development of a Recombinant DNA Assay System for the Detection of Genetic Change in Astronauts’ Cells  / 679
Susan V. Atchley, David J.-C. Chen, Gary F. Strniste, Ronald A. Walters, and Robert K. Moyzis

Flow Cytometry for Health Monitoring in Space  / 687
James H. Jett, John C. Martin, George C. Saunders, and Carleton C. Stewart

10 / SOCIETAL ISSUES 699

Dreams and Realities: The Future in Space  / 701
John Logsdon

The Budgetary Feasibility of a Lunar Base  / 711
Wallace O. Sellers and Paul W. Keaton

Lunar Stations: Prospects for International Cooperation  / 717
Phillip M. Smith

Soviet Lunar Exploration: Past and Future  / 725
James E. Oberg

Legal Responses for Lunar Bases and Space Activities in the 21st Century  / 735
Amanda Lee Moore

Extraterrestrial Law and Lunar Bases: General Legal Principles and a Particular Regime Proposal (INTERLUNE)  / 741
Christopher C. Joyner and Harrison H. Schmitt

Lunar Base: Learning to Live in Space  / 751
Ben Finney
Lessons from the Past: Toward a Long-Term Space Policy / 757
   Andrew Lawler

Historical Perspectives on the Moon Base—Cook and Australia / 765
   Eric M. Jones and Ben R. Finney

Space Poems: Close Encounters Between the Lyric Imagination and 25 Years of NASA
   Space Exploration / 771
   Helene Knox

11 / MARS 785

A Millennium Project—Mars 2000 / 787
   Harrison H. Schmitt

Mars: The Next Major Goal? / 795
   Elbert A. King

Rationales for Early Human Missions to Phobos and Deimos / 801
   Brian O’Leary

The Moons of Mars: A Source of Water for Lunar Bases and LEO / 809
   Bruce M. Cordell

The Problem of Water on Mars / 817
   Steven W. Squyres

12 / A VISION OF LUNAR SETTLEMENT 825

Lunar Industrialization and Settlement—Birth of Polyglobal Civilization / 827
   Kraft A. Ehricke

EPILOGUE: Address Given at Tricentennial Celebration, 4 July 2076, By Leonard
   Vincennes, Official Historian of Luna City / 857
   Ben Bova

INDEX 863