Key Elements of the Nation’s Vision

• Objectives
  – Implement a **sustained** and **affordable** human and robotic program
  – Extend human presence across the solar system and beyond
  – Develop supporting innovative technologies, knowledge, and infrastructures
  – Promote international and commercial participation in exploration

• Major Milestones
  – 2008: Initial flight test of CEV
  – 2008: Launch first lunar robotic orbiter
  – 2011 First Unmanned CEV flight
  – 2014: First crewed CEV flight
  – 2015: Jupiter Icy Moon Orbiter (JIMO)/Prometheus
  – 2015-2020: First human mission to the Moon
NASA APPROACH TO LUNAR “BASE” ACTIVATION

• 2004-2010: SPACE BIOMEDICAL RESEARCH AT ISS
• 2010?: SPACE SHUTTLE RETIREMENT
• 2004-2014: CEV “CONSTELLATION” & LUNAR ACCESS DEVELOPMENT
• 2008-2020: ROBOTIC MISSIONS TO EXPAND ON CURRENT KNOWLEDGE
• 2015-2020: DEMONSTRATE PERMANENT LUNAR INFRASTRUCTURE / PERMANENT HUMAN PRESENCE?
• 2015-202?: DEMONSTRATE EXTRACTION OF LUNAR RESOURCES
  – SPACE CONSUMABLES ONLY
• 202?-----: USE LUNAR RESOURCES FOR MORE COST-EFFECTIVE ACCESS TO SPACE

DETAILS IN-WORK

NASA 2004 PLAN / MARBURGER, 2/12/04
NASA APPROACH TO MARS
“BASE” ACTIVATION

• 2004-202?: USE ROBOTIC MISSIONS TO EXPAND ON CURRENT KNOWLEDGE

• 2015-202?: DEMONSTRATE AVAILABILITY OF LUNAR RESOURCES
  – SPACE CONSUMABLES ONLY

• 201?-202?: MARS ACCESS & EXPLORATION INFRASTRUCTURE DEVELOPMENT

• 202?------: USE LUNAR RESOURCES FOR MORE COST-EFFECTIVE ACCESS TO SPACE INCLUDING MARS

• 202?------: INITIATE HUMAN EXPLORATION

DETAILS IN-WORK

NASA 2004 PLAN / MARBURGER, 2/12/04
OR, THE PRIVATE SECTOR MIGHT DO SOMETHING A LITTLE MORE FOCUSED

EQUIPMENT AND PEOPLE

HELIUM-3 FUSION FUEL

FUSION POWER TECHNOLOGY

INVESTORS

BUSINESS MANAGEMENT

OPERATIONS MANAGEMENT

SETTLERS

FIRST HUMAN MISSION TO THE MOON: 10-18 YEARS AFTER REACHING INITIAL INVESTMENT MILESTONE OF $15 M.
INITIAL "BUSINESS" APPROACH TO LUNAR BASE ACTIVATION

- "BUSINESS" PLAN DEVELOPMENT
  - FINANCIAL COMMITMENTS**
  - COORDINATION WITH AND MARKETING TO RESOURCE USERS**
- DETAILED EVALUATION AND CHARACTERIZATION OF THE RESOURCE BASE
  - GRADE (CONCENTRATION)**
  - GEOTECHNICAL PARAMETERS**
- DEFINITION OF ENGINEERING DESIGN PARAMETERS FOR BASE AND MINING AND PROCESSING FACILITIES
  - MINE PLANNING**
  - DEVELOPMENT OF ARCHITECTURE AND ACTIVATION SEQUENCE**
  - LUNAR SURFACE EQUIPMENT REQUIREMENTS**
  - LAUNCH VEHICLE & SPACECRAFT REQUIREMENTS**
- FINAL DEFINITION OF LAUNCH AND SUPPORT ECONOMICS**
- COMMITMENT TO DETAIL DESIGN, MANUFACTURE, AND IMPLEMENTATION** FOR PRIVATE INITIATIVE, PROGRESS LIMITED UNTIL COMMERCIAL HE-3 FUSION DEMONSTRATED
<$1000/KG TO THE MOON VS. $57,000/KG
~100 TONNES TO THE MOON VS. 48 TONNES
PARTIALLY RE-USABLE? VS. EXPENDABLE
COMPARABLE RELIABILITY (~100%)
LONG TERM PRODUCTION VS. FIXED NUMBER
NO LONG TERM STAND DOWNS VS. APOLLO 13 & SHUTTLE

NEW SATURN VS. SATURN V:

NOTE: NASA’S INITIAL PLAN
IS TO USE COMBINATIONS
OF AVAILABLE ELVs WITH
EARTH-ORBIT ASSEMBLY
RISK, PRODUCTIVITY, AND COST MANAGEMENT -1: EQUIPMENT

** SHOULD APPLY TO NASA OR PRIVATE INITIATIVE

- NO LONG TERM STAND-DOWNS IN LAUNCHES TO MOON
  - FIRM BOOSTER DESIGN CRITERION
- LUNAR EQUIPMENT DESIGN
  - FAIL TO OPERATE (REDUNDANCY) > FAIL TO MANUAL > FAIL TO SAFE
- DESIGN LUNAR EQUIPMENT & FACILITIES WITH IMBEDDED DIAGNOSTICS
  - RAPID INSPECTION, REPAIR, AND UPGRADE

NASA’S PLANS ON THESE ISSUES NOT KNOWN AT THIS TIME
RISK, PRODUCTIVITY, AND COST MANAGEMENT -2: OPERATIONS

**SHOULD APPLY TO NASA OR PRIVATE INITIATIVE

**MAINTENANCE
- DESIGN AND OPERATE FOR PREDICTIVE AND PREVENTIVE MAINTENANCE
  - PART SELECTION, TESTING, AND INSPECTION
  - PRE-FAILURE PART REPLACEMENT
- DUST MANAGEMENT EMPHASIS IN DESIGN AND OPERATIONS**

**INVENTORY ALL DISCARDED OR UNUSED MATERIALS FOR FUTURE USE
- TOO VALUABLE TO THROW AWAY**

NASA’S PLANS THESE ISSUES
NOT KNOWN AT THIS TIME
RISK, PRODUCTIVITY, AND COST MANAGEMENT -3: PERSONNEL

• LUNAR STAY-TIME
  – PRIVATE INITIATIVE WOULD WANT SETTLERS AS LUNAR EMPLOYEES
    • RETURN COSTS ELIMINATED
• LUNAR WORK CYCLE
  – 12 HOUR SHIFTS, 2 HOUR OVERLAPS
  – 6 DAY WORK WEEKS
    • STAGGERED AFTER 2 MINER-PROCESSORS IN OPERATION
  – 24 DAY LUNAR WORK MONTH
  – 13 LUNAR WORK MONTHS
    • ONE LUNAR MONTH R&R / YEAR AS SOON AS SETTLEMENT PRODUCTION RATES PERMIT
• TERRESTRIAL OPERATIONAL WORK CYCLE
  – DESIGNED TO SUPPORT LUNAR REQUIREMENTS
RISK, PRODUCTIVITY, AND COST MANAGEMENT -4: HEALTH

• PHYSICIAN PRESENT ANYTIME EIGHT OR MORE PERSONS PRESENT
  – EARLY DEVELOPMENT OF LUNAR OCCUPATIONAL MEDICINE CRITERIA
  – ON-SITE RESEARCH PROGRAM

• INJURY OR ILLNESS TREATED AT THE BASE
  – REPLACEMENT OF CRITICAL FUNCTIONS BY TEMPORARY INCREASE IN WORK HOURS OF OTHER INDIVIDUALS
    • EARTH-BASED TELE-MEDICAL ASSISTANCE

• SOLAR FLARE RISK MANAGEMENT BY DESIGN, DAILY PLANNING, AND FORECASTING (?)
  – NOT JUST AN ACTIVE SUN (11 YEAR CYCLE) PROBLEM
RISK, PRODUCTIVITY, AND COST MANAGEMENT -5: STAFFING

• CORE STAFFING CONSTRAINTS (EACH 100 KG HELIUM-3/YEAR)
  – 4 OPERATOR-ENGINEERS PER MINER-PROCESSOR
  – 4 OPERATOR-ENGINEERS PER VOLATILE REFINERY
  – 2 GEOLOGIST-MINE PLANNERS
  – 2 OPERATIONS SUPPORT / PHYSICIANS
  – 2 OPERATOR-ENGINEERS FOR MAIN BASE PLANNING
  – 1 OPERATIONS DIRECTOR (SETTLEMENT MANAGER)
  – 1 EXPLORATION GEOLOGIST / DEP. OPERATIONS DIRECTOR
  – 16 TOTAL OR TWO SATURN VI LAUNCHES

• ADDITIONAL SKILLS WITHIN GROUP
  – POWER SYSTEMS
  – ENVIRONMENTAL CONTROL
  – EMERGENCY MEDICAL TREATMENT
  – ELECTRONIC SYSTEMS
  – RISK MANAGEMENT
RISK, PRODUCTIVITY, AND COST MANAGEMENT - 6: STAFFING

• CORE STAFFING CONSTRAINTS (5+ MINER-PROCESSORS)
  – 4 OPERATIONS SUPPORT PERSONNEL
  • OPERATOR-ENGINEERS AND OPERATIONS SUPPORT PERSONNEL CROSS-TRAINED
  • PERIODIC ROTATION
  – 2 SETTLEMENT OPERATIONS SUPPORT ENGINEERS
  – 2 LONG TERM PLANNING COORDINATORS
  – ANCILLARY BUSINESS MANAGERS AS REQUIRED

• CORE STAFFING CONSTRAINTS (15+ MINER-PROCESSORS)
  – 1 DEDICATED SETTLEMENT MANAGER
  – 2 ADVANCED TRAINING / CAREER TRANSITION MANAGERS
FUTURE SUIT DESIGN GOALS:

- >1/2 THE MASS
- >4 TIMES THE MOBILITY
- HAND DEXTERTITY = NORMAL
- ASSISTED GRIP GLOVES
- >100 CYCLES BEFORE REFURBISHMENT
- VACUUM CONNECT / DISCONNECT

NASA PHOTO
FUTURE ROVER DESIGN GOALS:

- Crew driving consumables
- Conversion to radiation shelter
- Indefinite life design
- Resource mapping capability
RISK, PRODUCTIVITY, AND COST MANAGEMENT - 7: SETTLER SELECTION

• CRITERIA TO CONSIDER
  – SKILL MIX AND CROSS-TRAINING
  – YOUTH AND TRAINING VS. AGE AND EXPERIENCE
  – PHYSICAL CAPABILITY
  – MEDICAL RISK ANALYSIS
  – PSYCHOLOGICAL RISK ANALYSIS
  – PHYSIOLOGICAL AND PSYCHOLOGICAL TOLERANCE TO SPACE ENVIRONMENT
  • SPACE STATION TOUR TO WEED OUT 2% WHO DON’T ADAPT ??
  – COMMITMENT TO SETTLEMENT
  – COMMITMENT TO ON-SITE HEALTHCARE VS. RETURN TO EARTH
BASE ARCHITECTURE -1
PRE-ACTIVATION REQUIREMENTS

• SET LUNAR BASE DESIGN GOALS
  – INDEFINITE SUPPORT OF HUMAN ACTIVITIES
  – NEAR-TERM OXYGEN AND HYDROGEN PRODUCTION
  – MID-TERM HE-3 PRODUCTION
  – LONG-TERM PRODUCTION OF NEEDED MATERIALS AND FOOD
  – ANCILLARY USES OF THE MOON (SCIENCE, TOURISM, ETC.)

• INITIAL FREQUENCY OF LAUNCHES TO THE MOON
  – ONE PER TWO LUNAR CYCLES (ASSUMES NEW SATURN VI BOOSTER)
  – ON-SITE CONSUMABLES SUFFICIENT TO MISS AT LEAST TWO RE-SUPPLY OPPORTUNITIES
BASE ARCHITECTURE -2
PRE-ACTIVATION REQUIREMENTS

• EQUIPMENT AND FACILITY DESIGNS
  – INDEFINITE LIFE THROUGH ANTICIPATORY MAINTENANCE
  – FINALIZED PRIOR TO BASE ACTIVATION

• SITE OF FIRST BASE
  – ACCESS TO HIGHEST GRADE HE-3 PROVEN RESOURCE
    • H₂ CONCENTRATION SECONDARY CRITERION
      – H₂ AND H₂O (O₂) PRODUCTION CAN OCCUR AT ANY LOCATION
BASE ARCHITECTURE -3

• GENERAL ARCHITECTURAL LAYOUT OF THE BASE CORE FINAL BEFORE THE FIRST LANDING
  – SUPPORT INITIAL MINING AND PROCESSING ACTIVITIES
  – PROVIDE LONG TERM SUPPORT FOR REGIONAL MINING AND ANCILLARY BUSINESSES

• LANDING AND LAUNCH OPERATIONS WILL BE LOCATED AND DESIGNED SO AS TO NOT DISRUPT OTHER ACTIVITIES OR OTHER ACTIVITIES
  – DUST CONTROL

• ROADS AND WALKWAYS WILL BE STABILIZED
  – DUST CONTROL
BASE ARCHITECTURE -4

- LANDER PROPULSION MODULES AND RESOURCE TRANSFER MODULES WILL BE ACCESSIBLE TO REFUELING AND LOADING FACILITIES
  - LAND TO BEACON OFFSET
  - RESOURCE TRANSFER MODULES TRADE STUDY
    - LAUNCH MODE
    - MASS PER LAUNCH: VALUE VS. RISK VS. PRODUCTION RATE VS. CONSUMPTION RATE

- APPROPRIATE CRATERS RESERVED FOR CRYOGENIC STORAGE OF LUNAR CONSUMABLES
  - BURIED, INFLATABLE “BALLOONS”
  - PASSIVE, REGOLITH INSULATION
    - PASSIVE, RADIATIVE COOLING TO DEEP SPACE ??
Regional Mining Plan Utilizing Spiral Mining Systems

Spiral Mining Site
Volatile Storage Site
Road

Blocky Rim Crater
Plus One Crater Diameter Of Ejecta

Spiral Mining Tract
Volatile Resource Region

Main Support Base
WISCONSIN MARK 2 MINER CONCEPT
(RECTILINEAR MINING MODE)

DEVELOP LOOK-AHEAD RADAR FOR BURIED BOULDER DETECTION
MARK 2 RE-DESIGN ISSUES -1

1. SPIRAL VS. LINEAR VS. ?
   • COST / KG
   • OPERATIONAL RISK
   • PAYLOAD MASS TO MOON

2. ELECTRICAL POWER SYSTEM
   • H₂-O₂-SOLAR CLOSED CYCLE FUEL CELL
   • PHOTOVOLTAIC
   • SOLAR THERMAL
   • FISSION REACTOR

3. REGOLITH HEATING SYSTEM (IMPACTS #2 ABOVE)
   • SOLAR THERMAL
   • MICROWAVE-ELECTRIC
   • FISSION THERMAL
MARK 2 RE-DESIGN ISSUES -2

- CONSIDERATIONS OF REGOLITH GEOTECHNICAL PARAMETERS
  - SPECIFIC GRAVITY
  - CONCENTRATION OF FINES (<100 MICR0NS)
  - “ROCK”** DISTRIBUTION
  - CONCENTRATION OF INDURATED REGOLITH FRAGMENTS
  - CONCENTRATION OF FeS (VERY LOW BUT PRESENT)
  - COHESIVENESS / INTERNAL FRICTION
  - ABRASIVENESS
  - HYDROGEN EFFECTS (IF ANY)
  - WATER EFFECTS (IF ANY) IN PROCESSOR
  - DUST EFFECTS IN PROCESSOR

**ROCK FRAGMENTS TO LARGE TO BE PROCESSED IN MINER-PROCESSOR
MARK 2 RE-DESIGN ISSUES -3

1. PRE-PROCESSING AGITATION LOSSES
   • ~37% He LOST BETWEEN MOON AND LAB

2. PROCESSING SYSTEM
   • CRUSHING OF INDURATED FINES - YES OR NO
   • SEPARATION OF FINE FRACTION
   • RECOVERY OF AGITATION VOLATILE RELEASES
   • WASTE HEAT RECOVERY - YES OR NO

3. LARGE ROCK OR ROCK FIELD AVOIDANCE
   • LOOK-AHEAD RADAR
   • SINGLE ROCK REMOVAL - MINER VS. “BULLDOZER”
MARK 2 RE-DESIGN ISSUES -4

1. MAINTENANCE IMPACT ON DESIGN
   • IMBEDDED DIAGNOSTICS
   • ANTICIPATORY COMPONENT REPLACEMENT
   • FAIL TO OPERATE, FAIL TO MANUAL, FAIL TO SAFE
   • REFURBISHMENT SCHEDULE

2. DUTY CYCLE
   • MAINTENANCE REQUIREMENTS
   • PERSONNEL WORK / REST / R&R CYCLE

3. TERRESTRIAL MINING-PROCESSING BENCHMARKS ??
   • CONCEPTUAL APPROACHES TO TERRESTRIAL MINING
   • ALTERNATIVE, LOW MASS STRUCTURAL MATERIALS
   • CONTROLS AND AUTOMATION POTENTIAL
   • LONG-TERM MINING RATES
   • MAINTENANCE ISSUES
OPERATIONAL SUPPORT -1

- POWER PRODUCTION / CONVERSION TRADES STUDIES
  - ACTIVATION PHASE:
    - SOLAR ENERGY + BATTERIES + RHUs
    - SOLAR ENERGY + BATTERIES + RTGs
    - H₂ + O₂ FUEL CELL WITH SOLAR RECYCLING OF H₂O
  - INITIAL He-3 PRODUCTION PHASE (O₂ AND H₂ BY-PRODUCT):
    - SOLAR ENERGY
    - H₂ + O₂ FUEL CELL WITH SOLAR RECYCLING OF H₂O
    - FISSION REACTOR
  - NORMAL PRODUCTION PHASES AND SELF-SUFFICIENT SETTLEMENT:
    - FISSION REACTOR
    - He-3 FUSION
    - SOLAR ENERGY AND FUEL CELLS FOR SPECIAL PURPOSES
OPERATIONAL SUPPORT -2

• HUMAN CONSUMABLES FROM LUNAR SOURCES
  – AS EARLY AS FEASIBLE:
    • PHASE-IN LUNAR PRODUCTION UNTIL INDEFINITE SUPPORT ACHIEVED

• REAL-TIME OPERATIONAL / BUSINESS SUPPORT
  – BUSINESS MANAGEMENT: INITIALLY EARTH-BASED WITH TRANSITION TO MOON
  – MARKETING AND SALES: EARTH-BASED WITH EARTH-MOON COORDINATION
  – PRODUCT RECOVERY AND DISTRIBUTION: EARTH-BASED
  – RESEARCH AND DEVELOPMENT: EARTH-BASED WITH LONG-TERM TRANSITION TO MOON
  – EARTH LAUNCH: EARTH-BASED
  – TRANS-LUNAR, MOON LAUNCH AND TRANS-EARTH: MOON-BASED
  – BASE AND MINING ACTIVITIES: MOON-BASED
  – HEALTHCARE: MOON-BASED
SATURN VI BOOSTER
PAYLOAD MANIFEST -1

SVI-1U*
- MOBILE STATION 1
  - POWER MODULE
  - HABITATION FOR 16
    - OPERATIONS SUPPORT
  - VOLATILE REFINERY
  - RAD-SHIELD ENVELOPE
  - CRYOGENIC STORAGE
  - MOBILITY SYSTEM
- OFF LOADING SYSTEM
- CONSUMABLES
  - POWER START-UP
    - HYDROGEN
    - OXYGEN

SVI-2U
- MINER-PROCESSOR 1
- CONTROL-TRANSFER ARM
- MULTIPURPOSE ROVER 1
  - AGGREGATE SEPARATOR
  - REGOLITH IMPELLER
  - EARTH MOVER
  - EVA CONSUMABLES
  - RESOURCE MAPPING
  - REMOTE RAD-SHIELD
- OFF LOADING SYSTEM
- CONSUMABLES
  - FOOD
  - OXYGEN

* SVI-1U: SATURN VI UNMANNED LAUNCH
<table>
<thead>
<tr>
<th>SATURN VI BOOSTER PAYLOAD MANIFEST -2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SVI-1M</strong></td>
</tr>
<tr>
<td>• SETTLER LANDING MODULE*</td>
</tr>
<tr>
<td>– 2 ENGR / OP FOR M-P</td>
</tr>
<tr>
<td>– 2 ENGR / OP FOR VR</td>
</tr>
<tr>
<td>– 1 GEO / MINE PLANNER</td>
</tr>
<tr>
<td>– 1 OP SUP / PHYSICIAN</td>
</tr>
<tr>
<td>– 1 EXPL GEO / DEP OPS DIR</td>
</tr>
<tr>
<td>– 1 OPS DIRECTOR</td>
</tr>
<tr>
<td>• CONSUMABLES MODULE</td>
</tr>
<tr>
<td><strong>SVI-2M</strong></td>
</tr>
<tr>
<td>• SETTLER LANDING MODULE*</td>
</tr>
<tr>
<td>– 2 ENGR / OP FOR M-P</td>
</tr>
<tr>
<td>– 2 ENGR / OP FOR VR</td>
</tr>
<tr>
<td>– 1 GEO / MINE PLANNER</td>
</tr>
<tr>
<td>– 1 OP SUP / PHYSICIAN</td>
</tr>
<tr>
<td>– 1 EXPL GEO / DEP OPS DIR</td>
</tr>
<tr>
<td>– 1 OPS DIRECTOR</td>
</tr>
<tr>
<td>• CONSUMABLES MODULE</td>
</tr>
</tbody>
</table>

* DESIGNED AS MODULAR COMPONENT FOR MAIN BASE OR FOR RE-USE
** SATURN VI MANNED LAUNCH
FIRST TWO MANNED MISSIONS OBJECTIVES

SVI-1M
- Activate Rover
- Fill Rad-Shield Envelope
- Activations
  - Power Module
  - Habitation Module
    - Operations Support
  - Volatiles Refinery
  - Cryogenic Storage
  - Mobility System
- Verify Resource Grade at Mine Site 1
- Move Station to Mine Site 1

SVI-2M
- Move Miner-Processor & Control-Transfer Arm to Mine Site 1
- Imbed Miner-Processor
- Connect Control-Transfer Arm
- Test & Calibrate Miner-Processor
  - Test & Calibrate Volatiles Refinery
- Initiate Volatiles Production
- Lay-Out Main Settlement Site
## SATURN VI BOOSTER PAYLOAD MANIFEST -3

### SVI-3U
- MOBILE CRANE / CARRIER
- MAIN BASE INFRASTRUCTURE COMPONENTS
- AGRICULTURAL PRODUCTION COMPONENTS
- MULTIPURPOSE ROVER 2
- REGOLITH WATER STORAGE SYSTEM
- REGOLITH OXYGEN PRODUCTION SYSTEM
- OFF LOADING SYSTEM

### SVI-3M
- SETTLER LANDING MODULE
  - 2 ENGR / OP FOR MAIN BASE
  - 2 ENGR / OP FOR FARM
  - 1 GEO / EXPLORATION
  - 1 BASE OPERATIONS SUPERVISOR
  - 1 SCI / AGRI ENGR
  - 1 BASE MGR
- CONSUMABLES MODULE
  - FOOD
  - HYDROGEN
  - OXYGEN
THIRD MANNED MISSION
OBJECTIVES

• MOVE MAIN BASE COMPONENTS TO PLANNED LOCATIONS
  – CONSTRUCT REGOLITH RAD-SHIELDS
• INTEGRATE 3 MANNED LANDER CABINS WITH MAIN BASE INFRASTRUCTURE
  – CONSTRUCT REGOLITH RAD-SHIELDS
• MOTHBALL 6 LANDER PROPULSION MODULES
  – ENABLE USE OF TANKS FOR INITIAL HYDROGEN & OXYGEN STORAGE
• ACTIVATE AGRICULTURAL PRODUCTION SITE
  – FILL REGOLITH RAD-SHIELD ENVELOPE
• INSTITUTE DISPUTE / CRIME RESOLUTION SYSTEM (POSSIBLE APPROACH)
  – SETTLEMENT MANAGER FINAL ADMINISTRATIVE AUTHORITY AFTER PEER RECOMMENDATION
  – APPEAL THROUGH CIVIL COURTS ON EARTH IF APPROVED BY MAJORITY OF SETTLERS
COST-TRADE STUDIES

• MINE PLANNING AND FACILITY DESIGNS WITH EXISTING DATA BASE VS. OBTAINING MORE DATA
• LAUNCH RATES VS. CREW OBJECTIVES VS. CREW SIZE DURING ACTIVATION
• ESTIMATED COST / TONNE COMPARING MINING STRATEGIES
• PERCENTAGE MINABLE REGOLITH LEFT UNMINED VS. MARGINAL COSTS TO MINE
• USE OF SUPPLEMENTAL EQUIPMENT, E.G., BULLDOZERS TO CLEAR BOULDER FIELDS VS. MINE AROUND
• BALANCE BETWEEN EXTRACTION AND REFINING AND SHIPMENT MASS AND STORAGE
• CHEMICAL VS. ELECTROMAGNETIC LAUNCH TO EARTH
• ROBOTIC VS. TELE-ROBOTIC VS. CREW ASSISTED OPERATIONS
• STORAGE VS. THROW-AWAY WITH RESPECT TO BY-PRODUCTS
• LOGISTICAL SUPPORT COSTS: IMPORTS VS. RAPID DEVELOPMENT OF LUNAR RESOURCES
AGRICULTURAL RESEARCH -1

- HIGH PRIORITY ACTIVITY
  - REDUCE COST OF BASE SUPPORT
  - DEMONSTRATE SELF-SUFFICIENCY
- LIGHTING DESIGN
  - Protect crops from radiation
  - Maximize use of solar energy
- HYDROPONICS VERSUS “TRADITIONAL” TECHNIQUES
- REQUIRED NUTRIENTS
  - Lunar sources
- PLANT / ATMOSPHERE / HABITAT SYSTEM
  - Minimize required consumable augmentation
AGRICULTURAL RESEARCH -2

• SOIL AND WATER ADDITIVES AS FUNCTION OF TIME
  – ORGANIC WASTE, WATER AND CARBON DIOXIDE RECYCLED
  – LUNAR NUTRIENTS SOURCES
    • REGOLITH
    • PYROCLASTICS
    • KREEP
• EVALUATE EXPORT ECONOMICS
  – SPACE STATIONS
  – DEEP SPACE MISSIONS
  – ANCILLARY SUPPORT ACTIVITIES
ANCILLARY SUPPORT ACTIVITIES

- LUNAR AND PLANETARY SCIENCE STATION
- SOLAR SYSTEM OBSERVATORY
- BASIC PHYSICS RESEARCH CENTER
- FAR-SIDE RADIO AND OPTICAL OBSERVATORY
- TERRESTRIAL METEOROLOGY CENTER
- DEEP SPACE MISSION OPERATIONS CENTER
- ONE-SIXTH GRAVITY SPACE PHYSIOLOGY RESEARCH CENTER
- ONE/SIXTH GRAVITY MATERIALS RESEARCH CENTER
- TOURIST FACILITY
- ARCHIVAL FACILITY
“CULTURAL” DESIGN CONSIDERATIONS -1

• HABITAT AND INDOOR WORKING FACILITIES PERSONNEL FRIENDLY
  – ELECTRONIC, REALTIME WINDOWS
  – PIPED IN NATURAL LIGHT
  – PRIVACY AREAS
  – PERSONAL GARDEN PLOTS
  – INDIVIDUAL AND PRIVATE VOICE AND ELECTRONIC COMMUNICATIONS BACK TO EARTH
  – INTERNAL RECREATION FACILITY

• PLAN FOR EXTERIOR RECREATION
  – ADDITIONAL DEMAND ON SPACE SUIT LONGEVITY AND RELIABILITY
“CULTURAL” DESIGN CONSIDERATIONS -2

• DETERMINE LONG TERM SUITABILITY OF 1/6 GRAVITY FOR INDIVIDUALS AND FAMILIES
  – BIOMEDICAL RESEARCH IN LONG TERM EFFECTS
  – BIOMEDICAL RESEARCH IN CHILD PHYSICAL DEVELOPMENT
  – BIOMEDICAL RESEARCH IN OCCUPATIONAL MEDICAL PRACTICE
  – RE-ADAPTATION PROTOCOL FOR RETURN TO EARTH

• FINANCIAL / POLITICAL INCENTIVES FOR ENTERPRISE OWNERSHIP
  – STOCK AND STOCK OPTIONS
  – GOVERNANCE REPRESENTATION
  – LONG TERM PLAN FOR SELF-GOVERNANCE OF SETTLEMENT
  – SETTLER-FUNDED “RETURN TO EARTH” INSURANCE ?
Correlation of Helium Content With TiO2 in Lunar Regolith
The Concentration of Helium-3 Correlates Quite Well With the Product of Maturity and Ti Content

\[ y = (0.2043)x^{0.645} \]
\[ r^2 = 0.911 \]

Source: L. A. Taylor, p. 49 in 2nd Wisconsin Symposium on Helium-3 and Fusion Power, 1993
Clementine Global Albedo Images
(750 nm filter)

Near Side

Far Side
ARROW POINTS TO SERENITATIS BASIN.
NOTE THAT CENTER IS IRON-RICH BUT TITANIUM-POOR
TITANIUM DISTRIBUTION BASED ON REMOTE SENSING FROM EARTH

TRANQUILLITATIS
ARROWS INDICATE MAIN AREA OF AGREEMENT


LUNAR PROSPECTOR

Thermal Neutrons (counts)

NORTH POLE

SOUTH POLE

MID-LATITUDES

TRANQUILLITATIS
Medium Energy Neutron Distribution
Lunar Prospector

NOTE: REDUCTION IN NEUTRON COUNT IS
MEASURE OF HYDROGEN DISTRIBUTION
MISSION RULES:
CREW SAFETY, SUCCESSFUL ACTIVATION EMPHASIZED IN EARLY PHASES
MAINTAIN SPARE ASCENT MODULE ON SURFACE UNTIL BASE CAPABLE OF SUPPORTING CREWS INDEFINITELY
MAINTAIN INVENTORY OF CONSUMABLES SUFFICIENT TO LAST TWO LUNAR CYCLES (I.E., ONE MISSED RESUPPLY)

ASSUMED TOURS OF DUTY FOR ACTIVATION CREWS
FIRST YEAR: 3 LUNAR CYCLES
SECOND YEAR: 6 LUNAR CYCLES
THIRD AND SUBSEQUENT YEARS: 12 LUNAR CYCLES
FIFTH YEAR: OPTION TO SETTLE

WORK CYCLE
10 HOUR DAYS AND SIX DAY WEEKS
SPLIT SHIFTS DURING CREW OVERLAPS