N93-26395

REPRESENTATIVE SYSTEMS FOR SPACE EXPLORATION

Scott R. Graham
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

OUTLINE

- OVERVIEW OF THE SYNTHESIS REPORT

- SPECIFIC ARCHITECTURE IV IMPLEMENTATIONS

- SPECIFIC POWER SYSTEM/ENVIRONMENT ISSUES

BACKGROUND

- **Synthesis Group was created in June 1990 to evaluate Outreach results and to establish a politically viable foundation**
  - **Architectures**
  - **Technology priorities**
  - **Early milestones**

- **Synthesis Report architectures are an excellent basis from which to proceed (appropriate framing parameters and range)**
  - **Associated priority technologies appear appropriate; assessment underway**

53, 54

PRECEDING PAGE BLANK NOT FILMED

RECOMMENDATIONS

(1) Establish within NASA a long range strategic plan for the nation's civil space program, with the Space Exploration Initiative as its centerpiece.

(2) Establish a National Program Office by Executive Order.

(3) Appoint NASA's Associate Administrator for Exploration as the Program Director for the National Program Office.

(4) Establish a new, aggressive acquisition strategy for the Space Exploration Initiative.

(5) Incorporate Space Exploration Initiative requirements into the joint NASA-Department of Defense Heavy Lift Program.

(6) Initiate a nuclear thermal rocket technology development program.

(7) Initiate a space nuclear power technology development program based on the Space Exploration Initiative requirements.

(8) Conduct focused life sciences experiments.

(9) Establish education as a principal theme of the Space Exploration Initiative.

(10) Continue and expand the Outreach Program.

PRIORITY TECHNOLOGIES

- Heavy lift launch with a minimum capability of 150 metric tons with designed growth to 250 metric tons
- Nuclear thermal propulsion
- Nuclear electric surface power to megawatt levels
- Extravehicular activity suit
- Cryogenic transfer and long-term storage
- Automated rendezvous and docking of large masses
- Zero gravity countermeasures
- Radiation effects and shielding
- Telerobotics
- Closed loop life support systems
- Human factors for long duration space missions
- Light weight structural materials and fabrication
- Nuclear electric propulsion for follow-on cargo missions
- In situ resource evaluation and processing

SYNTHESIS REPORT OVERVIEW OF ARCHITECTURES:

I - MARS EXPLORATION

II - SCIENCE EMPHASES FOR THE MOON AND MARS

III - MOON TO STAY AND MARS EXPLORATION

IV - SPACE RESOURCE UTILIZATION

MARS EXPLORATION

The major objective of this architecture is to explore Mars and provide scientific return. The emphasis of activities performed on the Moon is primarily as a preparation for the Mars mission, to test Mars equipment, systems and operations. This permits meaningful scientific return from the Moon.

Precursors		
		Moon: None Mars: Scout territory before committing to landing site
Lunar IOC	6 crew * 14 days 2006	Return safely to Moon, check equipment with second mission
Lunar NOC-1	6 crew 45-60 days 2007	Demonstrate extended operations through lunar night using Mars prototype equipment
Lunar NOC-2	6 crew 30 days 2009	Perform complete dress rehearsal for Mars; extended stay time in lunar orbit; obtain significant life sciences data
Mars IOC	6 crew 30-100 days 2014	Arrive at Mars and accomplish scientific exploration
Mars NOC	6 crew 600 days 2016	Achieve long surface stay to perform extensive field exploration, including addressing difficult and complex scientific problems; ISRU demonstrations

* Number of crew, surface stay time, launch date

- The dates are notional and depend upon available resources and technological development. (16)

SCIENCE EMPHASIS FOR THE MOON AND MARS

Balanced scientific return from the Moon and Mars. Emphasized throughout are exploration and scientific activities, including complementary human and robotic missions required to ensure optimum return.

Precursors		
		Moon: Global reconnaissance; landing site selection Mars: Global reconnaissance; geophysical and environmental measurements; site selection
Lunar IOC	6 crew * 14 days 2003	Demonstrate safe return with significant exploration capability; explore three complex sites; emplace experiments
Lunar NOC-1	6 crew 90 days 2006	Extend length of human presence; permanent crew- tended outpost; begin construction of lunar observatory
Lunar NOC-2	6 crew 180 days 2007	Longer stays; surface exploration; increase capability of observatory; experiment with life support system closure
Lunar NOC-3	6 crew 30 days 2008	Dress rehearsal for Mars mission; 200 day lunar orbit stay time (same as Architecture I)
Lunar NOC-4	18 crew extended 2010	Expand surface exploration and observatory capability
Mars IOC	6 crew 30-100 days 2014	Arrive at Mars and accomplish scientific exploration (same as Architecture I)
Mars NOC-1	6 crew 600 days 2016, 2018	Expand capability to conduct human field work
Mars NOC-2	12 crew 600 days 2020	Establish permanent base; emphasize exploration and science
Asteroid Option	6 crew 10-100 days (open)	Science includes mapping, sampling, emplacing; ISRU experiments

* Number of crew, surface stay time, launch date

- The dates are notional and depend upon available resources and technological development. (16)

MOON TO STAY AND MARS EXPLORATION

Permanent presence on the Moon and Mars exploration. Long term human habitation and exploration in space and on planetary surfaces provide terrestrial spinoffs to improve our life on Earth and increase knowledge of solar system and ourselves.

Precursors		
		Moon: Landing site selection; surface site characterization Mars: Global reconnaissance; site selection
Lunar IOC	6 crew * 14 days 2004	Establish crew-tended site and conduct survey work for a future permanent habitat; detailed site characterization
Lunar NOC-1	6 crew 40 days 2005	Remain for complete day/night cycle; establish infrastructure for permanent habitat
Lunar NOC-2	12 crew 90 days 2006	Emplace multiple habitats, accumulate life science data; demonstrate resource use, food production, recycle waste
Lunar NOC-3	18 crew 360 days 2007	Permanent presence; food production and life support system closure; in situ gas production; regular resupply and crew rotation
Lunar NOC-4	18 crew 30 days 2009	Mars dress rehearsal (same as in Architecture I)
Mars IOC	6 crew 30-100 days 2014	Arrive at Mars and accomplish scientific exploration (same as Architecture I)
Mars NOC	6 crew 600 days 2016	Achieve long surface stay to perform extensive field exploration, including addressing difficult and complex scientific problems; ISRU demonstrations (same as Architecture I)

* Number of crew, surface stay time, launch date

- The dates are notional and depend upon available resources and technological development. (16)

SPACE RESOURCE UTILIZATION

Make maximum use of available resources to support SEI missions. Seek to develop resources for transportation, habitation, life sciences, energy production, construction, etc. Reduce costs and approach self-sufficiency.

Precursors		
		Moon: Landing site selection for resource potential Mars: Site selection; surface characterization
Lunar IOC	6 crew * 14 days 2004	Select a resource-rich site and demonstrate in situ fuel production for use in rover and ascent vehicle.
Lunar NOC-1	6 crew 45-180 days 2006-2010	Small base, capable of expansion; demonstrates production of fuel, power beaming, etc.; build infrastructure
Lunar NOC-2	6 crew 40 days 2011	Dress rehearsal for Mars mission: extended lunar orbit stay time (500 days)
Mars IOC	6 crew 30-100 days 2016	Arrive at Mars and accomplish scientific exploration and ISRU experiments (same as Architecture I)
Mars NOC	6 crew 30-100 days 2018	Achieve long surface stay to perform tests and demonstrations of in situ resource use to support long term human presence
Asteroid Option	6 crew 10-100 days (open)	Emphasis on characteristics and examination of asteroid as a source of valuable, useful material

* Number of crew, surface stay time, launch date

- The dates are notional and depend upon available resources and technological development. (16)

SPECIFIC ARCHITECTURE IV IMPEMENTATIONS

- PRECURSORS
- TRANSPORTATION SYSTEMS
- SURFACE SYSTEMS

Space Resource Utilization Architecture
- Objective and Strategy -

ARCHITECTURE OBJECTIVE

Make maximum use of available resources to support the space exploration missions directly.

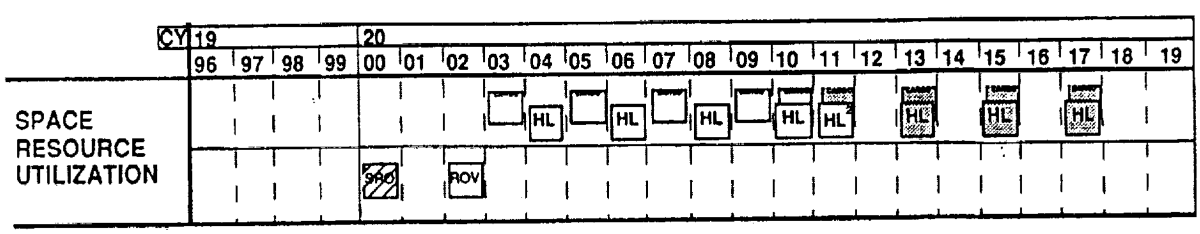
STRATEGY

"The goal is first to reduce the direct expense of going to the Moon and Mars, then to build toward self-sufficiency of long-duration space bases, and eventually to return energy and resources to Earth."

Space Resource Utilization Architecture
- Lunar Precursors and Robotics: Mission Strategy -

Strategy:

"...the location and quantities of resources on the Moon ... must be assessed. Some of this characterization is done remotely from Earth, but the general plan is to conduct robotic missions to map the Moon ... emphasizing resource location and quantification."



Reconnaissance orbiter (2)
- quantify mineralogy and chemistry
- surface topography (stereo visual imagery)
- regolith structure (electromagnetic sounder)
- electromagnetic noise background

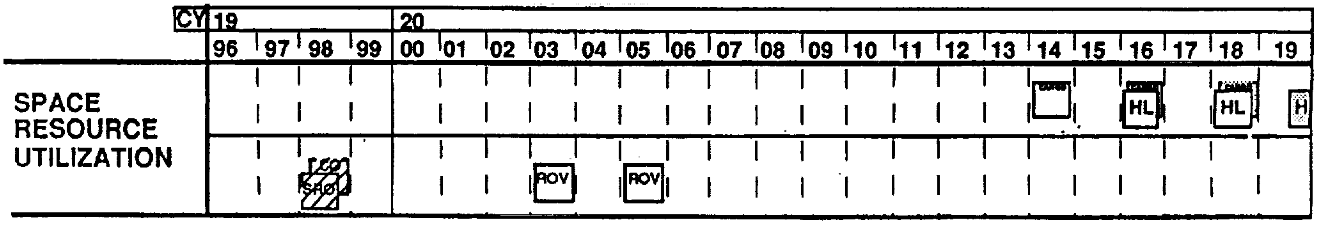
Telerobotic rover (1)
- locate resource deposits
- chemical and evolved gas analysis
- physical properties

Space Resource Utilization Architecture

– Mars Precursors and Robotics: Mission Strategy –

Strategy:

"The overall approach is to achieve knowledge of Mars from robotic missions and then to follow up with detailed field science by humans. ...robotic precursor missions are used to scout the territory before committing to a landing site. ... A minimum set of precursors is flown to gather the data necessary for selecting Mars landing sites.



Reconnaissance orbiter / Comm orbiter (2 each)

- image 12 candidate landing sites for certification
  - identify and map hazards
- chemical and physical properties
  - strategic science and resource data to aid site selection

Automated rover (2)

- test for toxicity
- chemical and mineral analysis
- image surface and subsurface

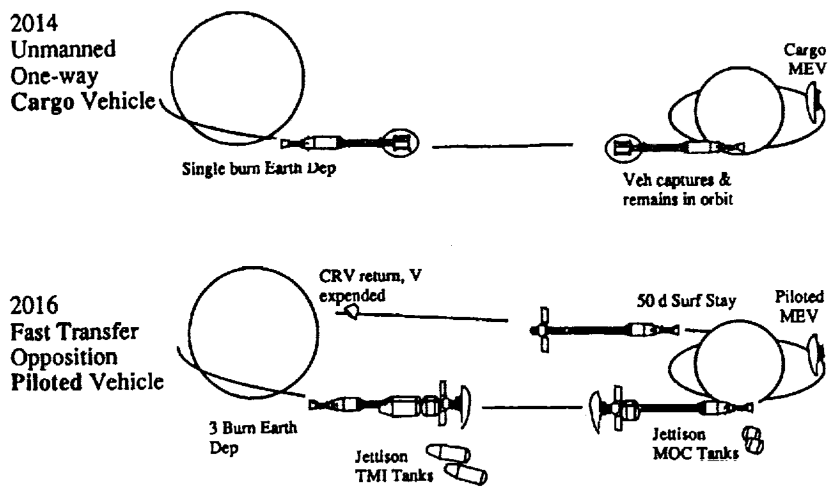
Mars Transportation System (MTS)

Assumptions & Approach

- **Mission Concept is a Split-Sprint Type**
  - **Piloted Flights in 2016 & 2018**
  - **Cargo-Only Flights in 2014 & 2016**
- **Earth-to-Orbit (ETO) Launch Capability is 250t Class**
  - **Cargo-Only MTS Flights Sized for Single ETO (Multiple Cargo Flights/Mission)**
  - **Piloted MTS Flights Utilize Multiple ETO's**
- **MTS Comprised of Transfer Vehicle (MTV) & Lander Vehicle (MEV)**
  - **MTV Uses Nuclear Thermal Propulsion (Isp = 925s)**
  - **MEV Uses Lox/Methane Propellant (Descent/Ascent Stages) & Descent Aerobrake**
  - **MEV Sized to Land 45t on Mars Surface**
  - **MTS is Zero-g Vehicle**
  - **MTS Elements are Expended on Each Mission - Except MEV is Reusable**
- **MTS Crew Modules Sized for Crew of 6**
  - **Ballistic Crew Recovery at Earth**
  - **Separate Transfer & Lander Crew Modules**
  - **Crew Launched By Shuttle**

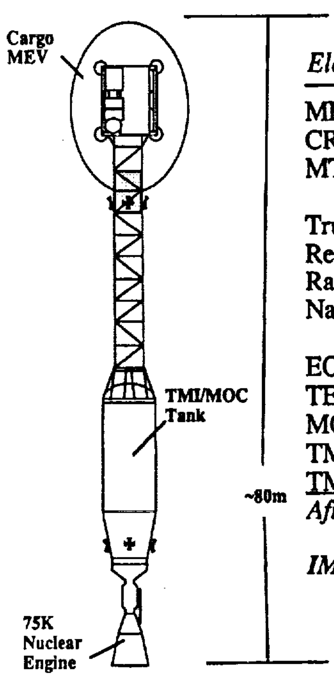
Space Resource Utilization Architecture

Split Sprint Mission Profile
2014/2016 First Mars Mission



Space Resource Utilization Architecture
2014 & 2016 One Way Cargo Mars Transfer Vehicles

Single MEV delivery

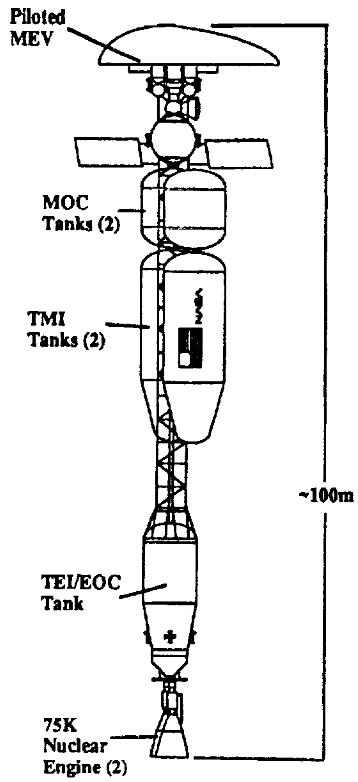


Element	*Mass (kg)*	*2014*	*2016*
MEV		78900	78900
CRV		0	0
MTV crew habitat system		0	0
Truss strongback, struts & RCS		5521	5521
Reactor/engine mass		3402	3402
Radiation shadow shield mass		0	0
Navigation pack mass		2000	2000
EOC propellant		0	0
TEI propellant		0	0
MOC propellant		22925	22630
TMI propellant		79236	75514
TMI/MOC common tank (1)		17797	17235
Aft tank total mass		119958	115379
IMLEO		209781	205202
		x2	x3
		419562	615606

* 2018 manned long stay conjunction requires 3 cargo MEVs,
2016 cargo: 3 NTR vehicles carrying 1 MEV each

Space Resource Utilization Architecture
2016 Opposition & 2018 Conjunction Piloted Mars Transfer Vehicles

2016 - 425 d transfer time, 50 d stay   2018 - 188 d transfer, 678 day stay



Element	*Mass (kg)* *2016*	*2018*
MEV	78900	78900
CRV	5808	5808
MTV crew habitat system	58000	58000
Truss strongback, struts & RCS	5521	5521
Reactor/engine mass	6804	6804
Radiation shadow shield mass	5598	5598
EOC propellant	0	0
TEI propellant	95281	80090
TEI/EOC common tank (1)	16873	14705
Aft tank total mass	112154	94795
MOC propellant	155260	116030
MOC tanks (2)	25002	20103
MOC tankset total mass	175620	136133
TMI propellant	314870	353880
TMI tanks (2)	49035	54360
TMI tankset total mass	363905	408240
IMLEO	**816943**	**796799**

Space Resource Utilization Architecture

Methane Lander Characteristics

Propellent Type: Cryogens, liquid oxygen, liquid methane

Rated Thrust: 30,000 lbf each

Number of descent engines: 5

Number of ascent engines: 3

Specific Impulse (vacuum): 380 sec

Total Loaded Mass: 78.9 metric tonnes

Landed Payload Capability: 45 metric tonnes

Space Resource Utilization - Mars IOC

Synthesis Group

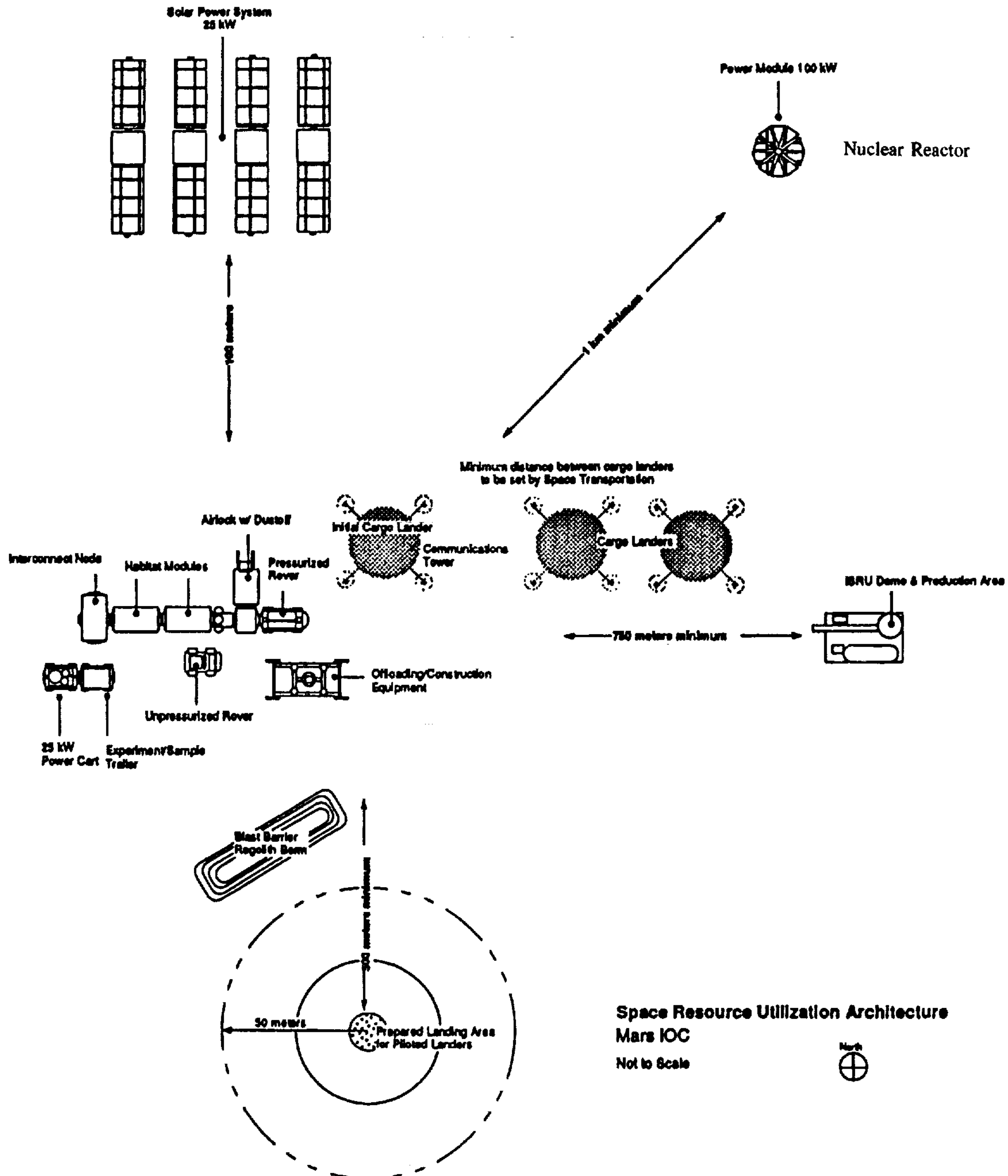
- Similar to Mars IOC of Mars Exploration Architecture

> - Arrive at Mars and successfully accomplish scientific exploration of its surface.
> - Predeployment of much of the needed equipment on the Martian surface and remote testing prior to crew launch
> - 30 - 100 day surface stay
> - Specified implementation utilizing:
>   - habitat (same design as the one tested on the lunar surface)
>   - pressurized rover
>   - nuclear power system
>   - minimal photovoltaic emergency backup
>   - unloader/mover
>   - scientific exploration equipment
>   - communications equipment

- Addition of resource utilization experiments on the Martian surface
  - Methane
  - Oxygen
- Specified implementation utilizing:
  - pressurized rover
  - habitat
  - atmosphere reduction plant

PSS Implementation

- PSS Objective
  Mars IOC establishes the infrastructure to support a crew of 6 on the Martian surface for up to 90 days.
- Major Elements Delivered
  Offloading/Construction Equipment
  Habitat Modules/Airlock
  Interconnect Node
  100 kW Power Module
  PVA/RFC Backup Power System
  Pressurized Rover
  CH_4/O_2 Unpressurized Rover
  ISRU Demonstration Unit
  Science
- Capabilities Provided
  - Habitat for a Mars surface crew of 6 for up to 90 days
  - Continuous power of 100 kW, with PVA backup
  - Pressurized transport on the surface with 100 km range
  - Payload unloading
  - Site preparation
  - Local unpressurized transportation capable of using locally produced fuel
  - Warning system for solar flares
  - Production of small quantities of CH_4, H_2O, O_2
- Issues
  Required habitat mass
  The required habitat mass exceeds payload constraints of Space Transportation, so habitat is delivered in multiple modules
  Delivery of elements 2 years prior to crew arrival
  Elements required to sit on the surface of Mars for 2 years before crew arrives



Cartoon—not based on any specific system's study.

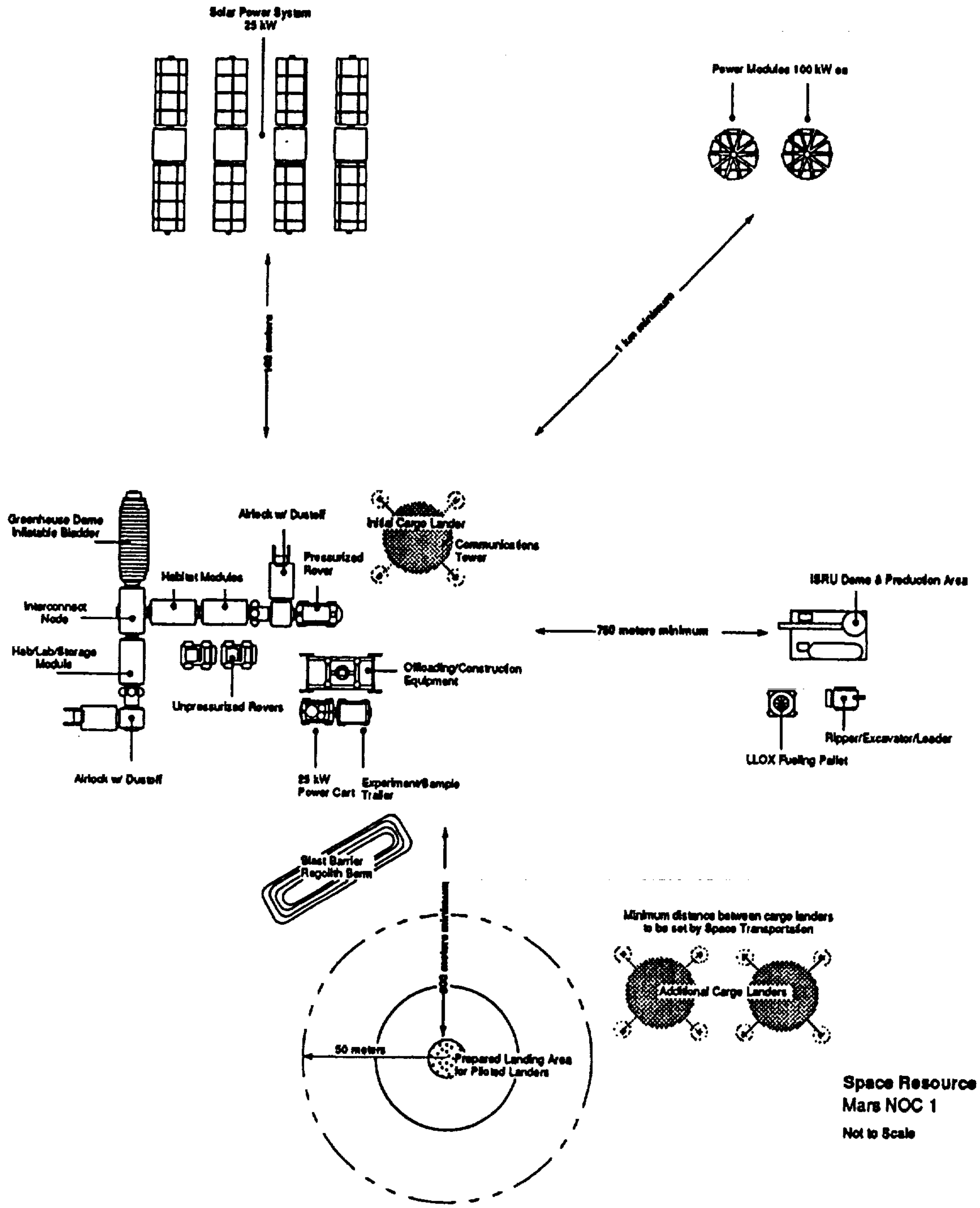
Space Resource Utilization - Mars NOC

Synthesis Group

- Emphasizes tests and demonstrations of in situ resource use on the Martian surface to support long term human presence
- Return to original site of Mars IOC
- Specified implementation utilizing:
  - resource plant expansion
  - small greenhouse

PSS Implementation

- PSS Objective
  Mars IOC objective is to carry out a 600 day crew stay at the site of the Mars IOC mission.
- Major Elements Delivered
  Hab/Lab/Storage Module
  Airlock
  100 kW Power Module
  Greenhouse
  Mars Atmosphere Processing Plant
  Integrated Mining Vehicle
  Fueling Pallet
  Unpressurized Rover
  Consumables
  Science
- Capabilities Provided
  - Habitat for a Mars surface crew of 6 for 600+ days
  - Continuous power of 200 kW, with PVA backup
  - Mining
  - Food production
  - Increased CH_4 production
- Issues
  Consumables
  The mass of the consumables needed (plus pallet) exceeds the allowable down mass for piloted flights. Consumables must have a "shelf-life" of 2 yrs.



Space Resource Utilization Architecture
Mars NOC 1
Not to Scale

SPECIFIC POWER SYSTEM/ ENVIRONMENT ISSUES

- WHAT SHOULD WE CONSIDER TO BE OUR MAXIMUM OPERATING VOLTAGES FOR SURFACE AND ORBITING POWER SYSTEMS? WHAT INCREASE IN VOLTAGE CAN BE ACHIEVED WITH INSULATION OF EXPOSED PARTS?
- WHAT CONCERNS ARE THERE WITH COPPER OR ALUMINUM CONDUCTORS, ON THE SURFACE? - OR IN ORBIT? (PROBABLY UPPER BOUNDED BY AREOSYNCHRONOUS ORBIT).
- WE ARE AWARE OF CO_2 AND REFRACTORY METALS INCOMPATABILITY- WHAT OTHER MATERIALS MAY EXPERIENCE EITHER CHEMICAL OR ELECTROCHEMICAL DECOMPOSITION?
- WILL A.C. (AS COMPARED TO D.C.) POWER TRANSMISSION REDUCE POSSIBLE STATIC BUILD UP AND SUBSEQUENT DUST BRIDGING ON EXPOSED POWER SYSTEM COMPONENTS SUCH AS, ARRAYS, CABLES, CONNECTORS OR INSULATORS? (MOON)
- WHAT SPECIAL GROUNDING TECHNIQUES MAY BE REQUIRED FOR SURFACE POWER SYSTEMS? (MOON)

CLOSING REMARKS

- CONCEPTUAL DESIGNS ARE CURRENTLY BEING DEVELOPED FOR LUNAR AND MARS POWER SYSTEMS.
- BOTH SOLAR AND NUCLEAR BASED SYSTEMS ARE VIABLE CANDIDATES PREDICATED PRIMARILY ON POWER LEVEL AND APPLICATION.
- SPECIFIC DESIGN DETAILS ARE SOMEWHAT LACKING BECAUSE ONLY TOP LEVEL INFORMATION IS AVAILABLE ON EACH ARCHITECTURE AT THIS TIME.
- A SYSTEMS APPROACH TO DESIGNING POWER SYSTEMS HAS BEEN ADOPTED AND WE CONSIDER THE EFFECTS OF VARIOUS SPACE ENVIRONMENTS TO BE A KEY FACTOR IN THAT APPROACH.