Outpost Science and Exploration Working Group (OSEWG)

Presented to LEAG 2007 Annual Meeting

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NASA Headquarters

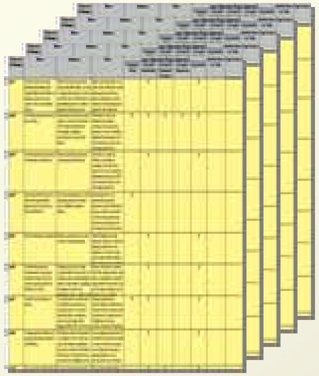
October 1, 2007

OSEWG Organization

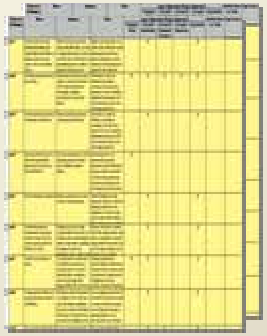
- Chartered jointly by ESMD and SMD in FY2007 to coordinate and guide outpost-related science and exploration planning
- Terms of Reference signed 3/07 by ESMD (Cooke and Yoder) and SMD (Hartman and Hertz)
- Working group reports to ESMD and SMD Deputy AAs
- Group co-chaired by ESMD Manager for the Lunar Architecture Team (Yoder) and SMD Lunar Program Scientist (Morgan/Snook)
- Core membership drawn from HQ and Constellation (Cx) and to include SOMD, ARMD, ESMD, and other organizational members as appropriate
- Jointly funded by respective Mission Directorates

Lunar Architecture Team Science Capability Focus Element Work Flow

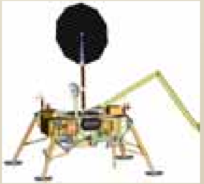
181 Objectives from Global Strategy Team



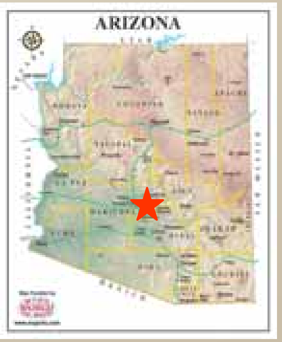
ALL Science Objectives
(45 "SMD" Science objectives + some others…)



Each Objective Deconstructed to Define Needed Capabilities and Mapped to Architecture



PRIORITIES from Tempe Workshop



Top Objectives

Grouped into key reference payloads

Mapped to Architecture options

LAT 2 Science Focus Element Team Accomplishments

- Worked extensively with science community at NAC Tempe Lunar Science Workshop to develop science priorities and science needs
- Using output of the Tempe workshop, developed a list of “Top Objectives” and Key Reference Payload Elements
- Pulled together basic parameters (mass, etc.) for Key Reference Payload Elements
- For 2 Reference Payload Elements, performed detailed assessments and preliminary engineering designs to further refine mass, power estimates and other issues
  - Lunar Environmental Monitoring Station
  - Lunar Telescope
- With OSEWG, held Workshop on Architecture Issues Associated with Sampling to work with Science community to assess needs for surface sample handling
- Worked with CAPTEM to assess requirements for returned sample mass, traceable to science objectives. Inserted risk into Cx system to investigate increase of sample mass return.
- Produced preliminary manifests for science in the Architecture Options
- With the Integration Team, developed Science Figures of Merit
- Supported the Integration Team in assessing sortie sties for science

PSS findings

Highest Ranking by PSS/LEAG:

- INTERNAL STRUCTURE and DYNAMICS - Geophysical/heat flow network - requires multiple sites, widely spaced (“global access”)
- COMPOSITION/EVOLUTION of LUNAR CRUST - requires extensive sampling at both local and diverse sites
- IMPACT FLUX - requires access to impact basins and sample return for age dating
- SOLAR EMISSIONS/GCR/INTERSTELLAR - requires drilling, regolith and core sample integrity, careful documentation
- CURATORIAL FACILITIES - development of sample documentation, environmental, and orientation controls needed
- SAMPLE ANALYSIS INSTRUMENTS AND PROTOCOLS - infrastructure for pristine sample collection, storage, documentation, and transport needed

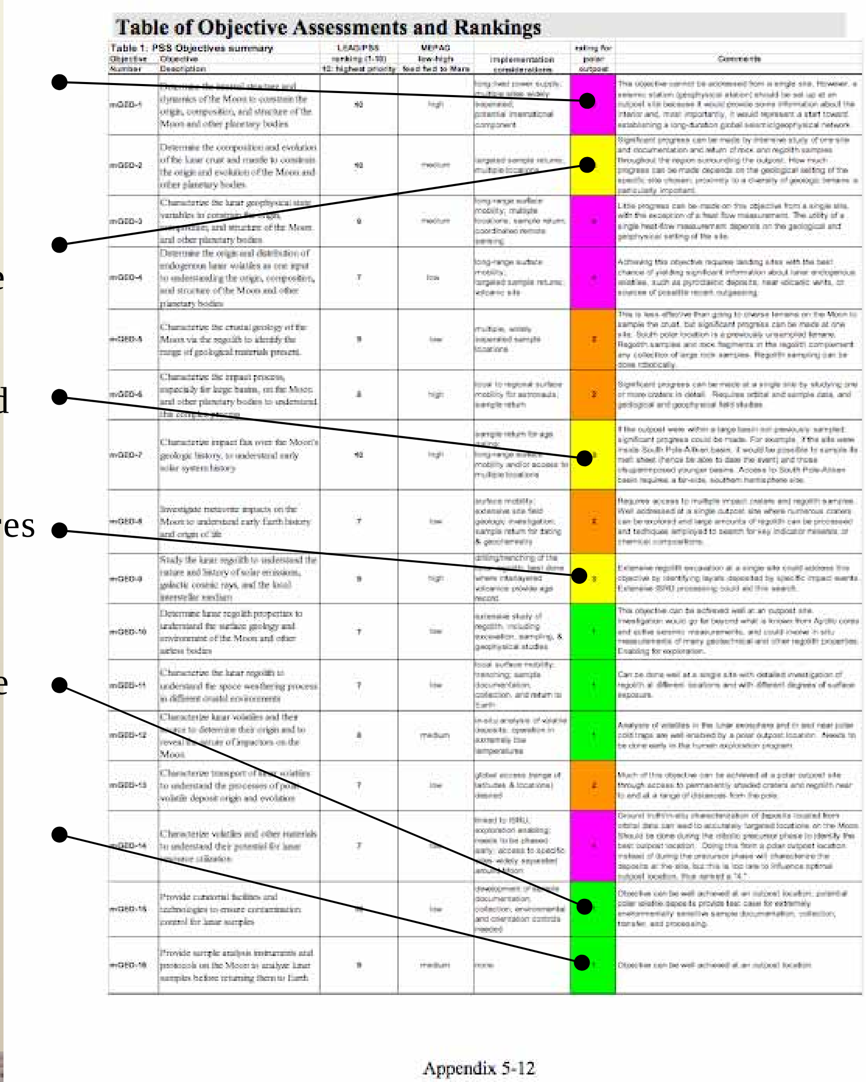


Table of Objective Assessments and Rankings

Table 1: PSS Objectives summary

Objective Number	Objective Description	LEAG/PSS ranking (1-10) 10: highest priority	MEPAG low-high feed fwd to Mars	implementation considerations	rating for polar outpost	Comments
mGEO-1	Determine the internal structure and dynamics of the Moon to constrain the origin, composition, and structure of the Moon and other planetary bodies	10	high	long-lived power supply; multiple sites widely separated; potential international component	[illegible]	This objective cannot be addressed from a single site. However, a seismic station (geophysical station) should be set up at an outpost site because it would provide some information about the interior and, most importantly, it would represent a start toward establishing a long-duration global seismic/geophysical network.
mGEO-2	Determine the composition and evolution of the lunar crust and mantle to constrain the origin and evolution of the Moon and other planetary bodies	10	medium	targeted sample returns; multiple locations	[illegible]	[illegible]
mGEO-3	Characterize the lunar geophysical state variables to constrain the origin, composition, and structure of the Moon and other planetary bodies	9	medium	long-range surface mobility; multiple locations; sample return; coordinated remote sensing	[illegible]	[illegible]
mGEO-4	Determine the origin and distribution of endogenous lunar volatiles as one input to understanding the origin, composition, and structure of the Moon and other planetary bodies	7	low	long-range surface mobility; targeted sample returns; volcanic site	[illegible]	[illegible]
mGEO-5	Characterize the crustal geology of the Moon via the regolith to identify the range of geological materials present.	9	low	multiple, widely separated sample locations	2	[illegible]
mGEO-6	Characterize the impact process, especially for large basins, on the Moon and other planetary bodies to understand the complex process	8	high	local to regional surface mobility for astronauts; sample return	2	[illegible]
mGEO-7	Characterize impact flux over the Moon's geologic history, to understand early solar system history	10	high	sample return for age dating; long-range surface mobility and/or access to multiple locations	[illegible]	[illegible]
mGEO-8	Investigate meteorite impacts on the Moon to understand early Earth history and origin of life	7	low	surface mobility; extensive site field geologic investigation; sample return for dating & geochemistry	2	[illegible]
mGEO-9	Study the lunar regolith to understand the nature and history of solar emissions, galactic cosmic rays, and the local interstellar medium	9	high	[illegible]	[illegible]	[illegible]
mGEO-10	Determine lunar regolith properties to understand the surface geology and environment of the Moon and other airless bodies	7	low	extensive study of regolith, including excavation, sampling, & geophysical studies	1	[illegible]
mGEO-11	Characterize the lunar regolith to understand the space weathering process in different crustal environments	7	low	local surface mobility; trenching; sample documentation, collection, and return to Earth	1	[illegible]
mGEO-12	Characterize lunar volatiles and their source to determine their origin and to reveal the nature of impactors on the Moon	8	medium	[illegible]	1	[illegible]
mGEO-13	Characterize transport of lunar volatiles to understand the processes of polar volatile deposit origin and evolution	7	low	global access (range of latitudes & locations) desired	2	[illegible]
mGEO-14	Characterize volatiles and other materials to understand their potential for lunar resource utilization	7	low	[illegible]	[illegible]	[illegible]
mGEO-15	Provide curatorial facilities and technologies to ensure contamination control for lunar samples	10	low	development of sample documentation, collection, environmental and orientation controls needed	1	[illegible]
mGEO-16	Provide sample analysis instruments and protocols on the Moon to analyze lunar samples before returning them to Earth	9	medium	none	1	Objective can be well achieved at an outpost location.

Appendix 5-12

OSEWG/LEAG Workshop on Architecture Issues Associated with Sampling

- Held June 25-26, 2007 in Houston
- ~80 participants - approximately half scientists, half engineers / managers
- Workshop Objectives:
  - to explore the problem of joint human and robotic sample return from other planetary surfaces
  - to identify key areas in which further study is needed
  - to begin dialogue between science and engineering communities on sample triage and the architecture issues associated with high-grading and curating samples
- Half day of presentations from LEAG, CAPTEM, MEPAG, OSEWG, Constellation, Apollo astronauts Jack Schmitt and John Young, Apollo Backroom scientists, curators, and sample scientists. Show and tell, Apollo sampling tools
- Remaining time in breakout and plenary discussions

OSEWG/LEAG Workshop Topics

Discussion breakouts - 7 groups went through identical discussion questions in the context of different lunar or Mars exploration scenarios (four lunar, three Mars scenarios) on end-to-end problem of sampling:

TRAVERSE PLANNING - Navigation, data requirements, field crew vs. ground team planning, crew time optimization, hab workspace requirements, teleoperations and robotic assistance

SAMPLE AND DATA ACQUISITION - Navigation, sampling strategies, sample preservation, in-situ measurements vs. sample collection, mass, power, and volume estimates.

DOCUMENTATION - Sample documenting automation - RF tagging or barcoding, Video/camera and audio requirements, real-time versus post documentation, time-stamping, real-time GIS capabilities in suit and/or rover

SAMPLE HIGH-GRADING - Concepts for optimizing mass returned, space and crew time requirements, robotic assistance, data requirements, rock garden/sample shed concepts, optimizing crew/ground interactions. Autonomous high-grading of samples in situ

LABORATORY ANALYSIS - Minimum and dream lab requirements (volume, functionality, sample preservation, glove box limitations, etc.), capabilities vs. mission duration, lab science vs. EVA science - optimizing crew presence

SAMPLE RETURN - Preserving sample integrity, mass/power/volume of returned sample masses (reports from recent studies)

CURATION - Surface sample handling, documentation, transport, storage

OSEWG/LEAG Workshop Results

- Ten outstanding questions to be refined and assigned to appropriate study groups (or incorporated into studies already planned)
- Key areas needing study:
  - Optimizing the **human-robotic partnership** for maximum exploration science return, minimum risk
  - Preserving **sample integrity** - special vs. traditional samples
  - Criteria for sample **triage**, high-grading, and subsampling - better definition of SHeD reqt's
  - **Navigation** and communication requirements for sample collection, documentation, subsampling, and curation
  - *In situ* field measurements and **surface lab** analysis vs. returned sample mass trade space
  - Using **analogs** and past mission lessons learned to address sampling issues and inform surface system design

OSEWG/LEAG Workshop Results (cont.)

- Workshop surprises / preliminary findings:
  - Controversy and healthy debate / disagreement over basic scientific and curatorial requirements
  - Strong opinion that returned samples should not come into contact with humans or habitat after collection in field
  - Strong support (and some trepidation) for tele-robotic capabilities for sample handling and surface curation with humans in hab or on Earth - telerobotics as human-extension tools rather than robot assistants

OSWEG Near Term Interests - Examples

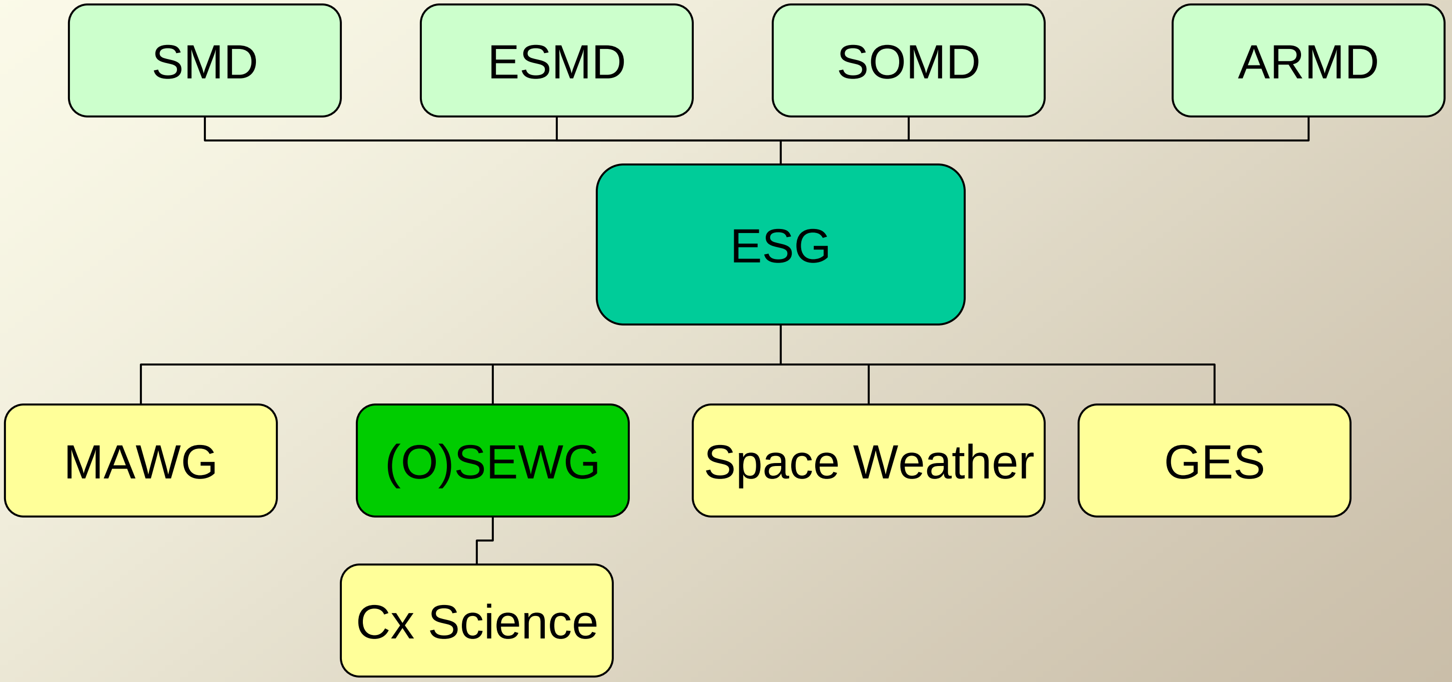
- Field requirements resolution
  - Field capture sample location – data collected and documentation
  - Locating sample area
- Sample mass return (100kg)
  - What can we do with 100kg?
  - What if we had an additional 50kg, etc?
- Lab requirements in hab
- Core tools
- Power requirements for return samples
- Power requirements for hab
- Power requirements for rover
- Communications requirements between astronaut and hab
- Communications between astronaut and rover
- Min science requirement for first missions
  - Handling systems etc
- Automation requirements

OSEWG Kick-off and Terms of Reference

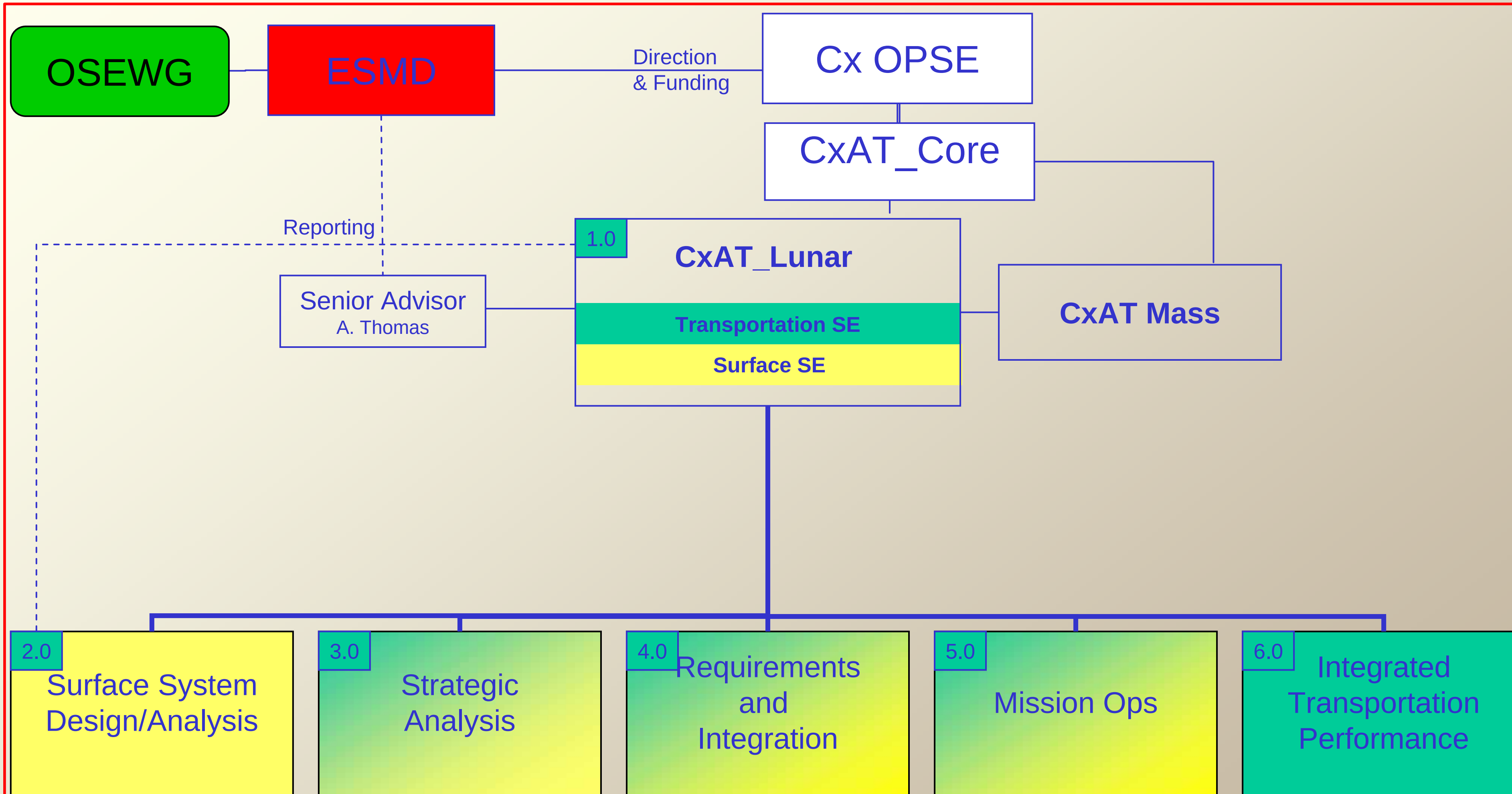
- OSEWG Kick-off meeting held at NASA HQ Sept. 26-27
- Three TORs identified as starting points
- Goal is to start with manageable tasks – validate the system process

1. Develop OSEWG roadmap for the next 5 years (high resolution for this year)
2. Analog Missions Coordination – included entry points, reviews, expected outcomes, etc.
3. Lunar Data Synthesis and Integration – ensures we are looking across the Lunar mapping resources i.e. LRO, Selene, MMM, etc.

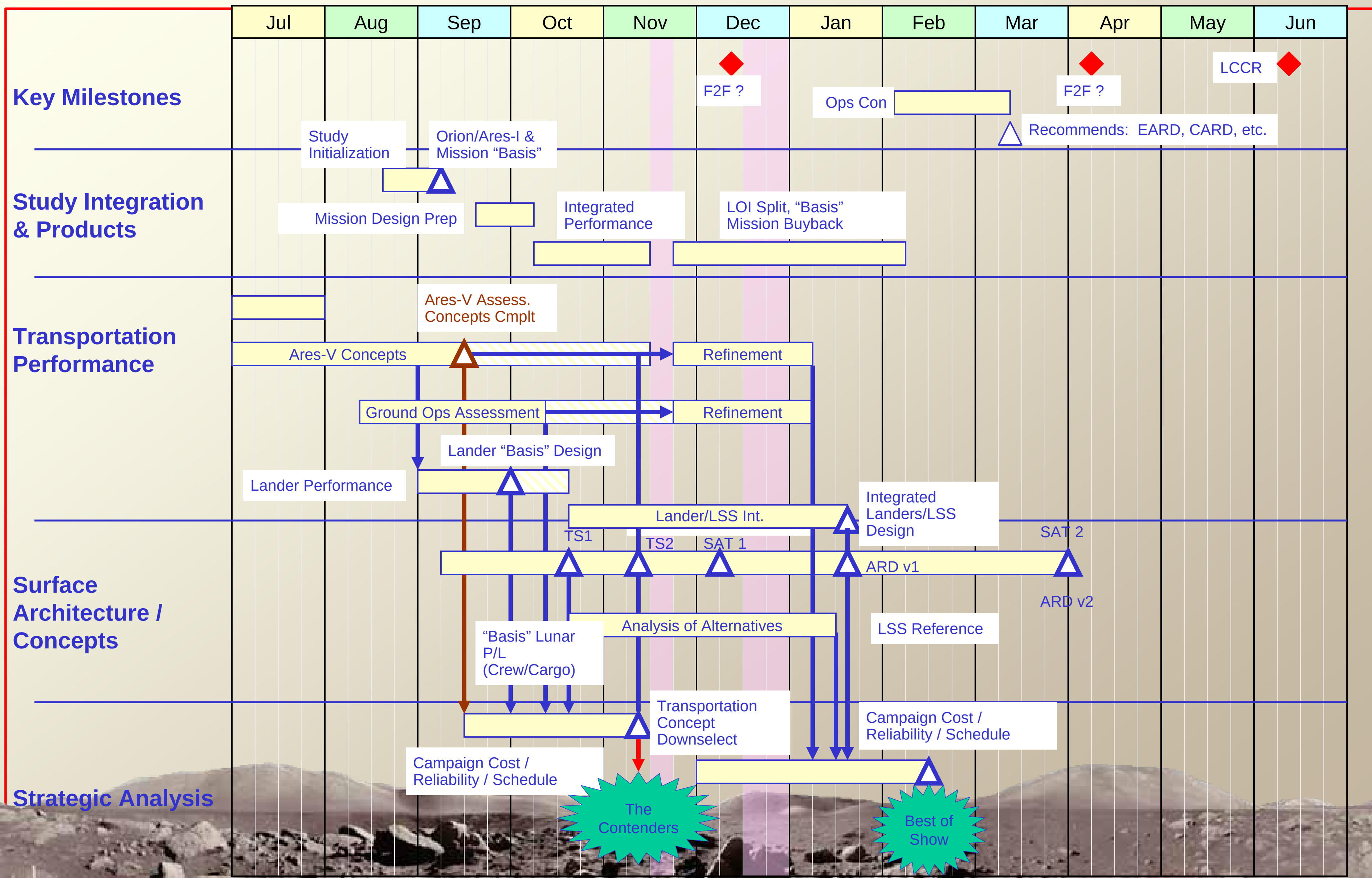
OSEWG Organization (cont.)



CxAT_Lunar Organization



Draft Schedule sensitive to Cx milestones



OSEWG Tasks and Responsibilities

- Analyze and develop outpost Design Reference Science Investigations (DRSIs) using a case approach
- Focus on evolving, time-phased outpost activities with maximum synergy - scientific return, and exploration benefit
- Inform ongoing calls for joint SMD / ESMD research programs (e.g. LASER)
- Flesh out outstanding unknowns related to science operations – payload and sample masses, EVA requirements, mobility, work-space and laboratory equipment, crew time, human / robotic optimization, etc.
- Identify new technology needs (Primarily Science related)
- Address exploration requirements as contained in Exploration Architecture Requirements Document (EARD)

Relationship of OSEWG to other groups

- CxAT Lunar – Supportive role for verifying and fleshing out outpost-related elements
- MAWG – Supportive role, particularly useful for ensuring good feed-foward and feed back to/from Mars architecture surface elements
- LEAG/MEPAG/CAPTEM/FEAT – Close working relationship – LEAG, MEPAG, CAPTEM, FEAT etc. can be tasked for studies requiring input from broad community base and expert groups

Analog Missions Coordination: Functions and Benefits

- **Learn**
  - Reduce risk to crews for human surface missions to the Moon and Mars
  - Learn what works and what doesn't work for surface science operations and exploration missions
  - Enable scientific advances in planetary and Earth studies
- **Test**
  - Validate surface mission designs: Long duration presence, Outpost buildup, Human & robotic roles, etc.
  - Demonstrate integrated use of products from multiple CxP projects
    - Validate hardware/software performance under realistic conditions, as commanded by crews and/or mission control
    - Identify performance shortfalls in systems and support iterative testing
  - Validate mission operations designs and functions for planetary missions
  - Influence engineering and payload system designs via early use in realistic situations
  - Enable **surface science** by demonstrating integration of science activities and payloads into surface exploration mission activities
- **Train**
  - Reduce risk to crews and to mission objectives
    - Improve crew and Mission Control team readiness for surface activities
    - Increase mission efficiency and effectiveness by evaluating competing approaches early
- **Engage**
  - Help sustain the excitement of exploration for the public well before missions become reality
  - Demonstrate accomplishment of key milestones to decision-makers

OSEWG Analogs Coordination

- Facilitate and document SMD / ESMD / SOMD / ARMD jointly-coordinated analog activities
- Provide analogs community with prioritized set of needs, requirements, oustanding problems needing investigation, and other points of feed-in to NASA mission planning processes
- Expand the database of usable analog sites, missions, and lessons learned by opening it to larger user community
  - A completely open Web Portal will be subject to NASA internal review and approval
  - Provide an on-line repository for analogues community (not just NASA) to store results of field deployments and research past deployments and associated lessons learned
  - Provide an assessment and characterization of usable analog sites
- Support and provide a forum for continued focused analog testing activities by ESMD, SMD, SOMD, or externally supported teams
- Coordinate with international analog science and engineering activities as appropriate

Analogs - Continuing Past Work

- Analogs "Tasker" begun within ESMD in 2005
- Analogs Database and Web Portal created and put on a "green" server
  - Web Portal is currently ID and Password protected
  - Ready to add Apollo-era training sites
  - Ready to incorporate EVA lessons-learned database compiled by NASA Astronaut Office
- Space Technology and Applications International Forum (STAIF) - Feb 2007
  - Primarily technology users and developers
- Invited Meeting at JSC ("First Analogs Workshop")
  - Timed to coincide with Lunar and Planetary Sciences Conference (LPSC), so primarily science user community but NASA analogue users also represented
- Initial "supplier" community meeting
  - Largely JSC-based long-standing analogues programs: Desert RATS, Haughton-Mars Program (HMP), and NASA Extreme Environment Mission Operations (NEEMO)
- ARDIG established as focal point for Constellation Program Office analogues activities
  - Launched "analogs initiative"
  - Begin coordination activity among JSC-based analogues groups: DRATS, HMP, and NEEMO

Website Layout Example – Home Page

Analogs
@ Johnson Space Center, Houston, Texas

+ Analogs Home	+ Feedback	+ What's New	+ PWD Change
+ AnalogsDB	+ SELL DB	+ Events	+ Logout

An analog is an activity performed in a representative environment that is similar to a feature of the target mission.

Analogs

Welcome to the Analogs website at Johnson Space Center. The purpose of this website is to serve as a source of information on and a collaboration tool for analogs activities; primarily, but not exclusively focusing on analogs relevent to NASA's exploration program's and the Vision for Space Exploration.

An analog mission is an analog activity that maps multiple features of the target mission in an integrated fashion to gain an understanding of system-level interactions.

This website is still in development and most sections will remain username/password restricted until a review of the website has been completed.

If you wish to participate in this review, please use the "+ Feedback" menu item to make a request for username/password.

Announcements:

The presentations from the workshop on March 10 are now available (no username/password required).

Please make sure that your passwords meet the following minimum requirements. The length must be at least 8 characters and contain at least one of each of the following: an uppercase letter, a lowercase letter, a number, and a special character.

An events calendar is now online for review through the "+ Events" menu link.

The prototype Surface Exploration Lessons Learned Database (SELL DB) is now online for review through the "+ SELL DB" menu link.

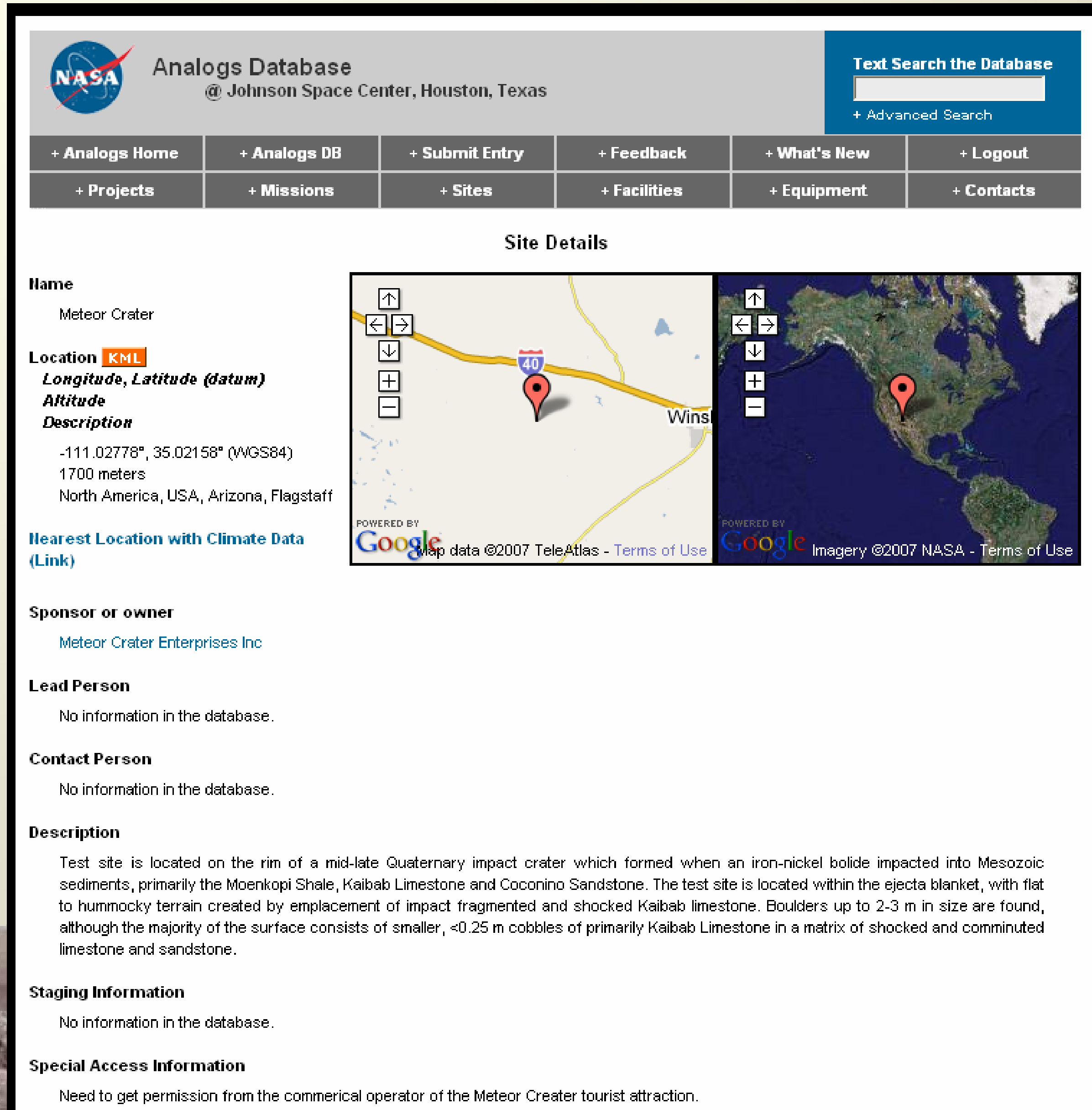
The prototype Analogs Database (AnalogsDB) is now online for review through the "+ AnalogsDB" menu link.

+ NASA Web Privacy Policy and Important Notices
+ Freedom of Information Act
+ Information-Dissemination Priorities and Inventories
+ Budgets, Strategic Plans and Accountability Reports
+ The President's Management Agenda
+ Inspector General Hotline
+ Equal Employment Opportunity Data Posted Pursuant to the No Fear Act
+ USA.gov

Curator: Stephen A. Voels
NASA Official: Brenda L. Ward
Last Updated: March 15, 2007

+ Contact Us

Website Layout Example - Analog Site



Analogs Database
@ Johnson Space Center, Houston, Texas

Text Search the Database
+ Advanced Search

+ Analogs Home | + Analogs DB | + Submit Entry | + Feedback | + What's New | + Logout
+ Projects | + Missions | + Sites | + Facilities | + Equipment | + Contacts

Site Details

Name

Meteor Crater

Location KML

Longitude, Latitude (datum)
Altitude
Description

-111.02778°, 35.02158° (WGS84)
1700 meters
North America, USA, Arizona, Flagstaff

Nearest Location with Climate Data (Link)

Sponsor or owner

Meteor Crater Enterprises Inc

Lead Person

No information in the database.

Contact Person

No information in the database.

Description

Test site is located on the rim of a mid-late Quaternary impact crater which formed when an iron-nickel bolide impacted into Mesozoic sediments, primarily the Moenkopi Shale, Kaibab Limestone and Coconino Sandstone. The test site is located within the ejecta blanket, with flat to hummocky terrain created by emplacement of impact fragmented and shocked Kaibab limestone. Boulders up to 2-3 m in size are found, although the majority of the surface consists of smaller, <0.25 m cobbles of primarily Kaibab Limestone in a matrix of shocked and comminuted limestone and sandstone.

Staging Information

No information in the database.

Special Access Information

Need to get permission from the commerical operator of the Meteor Creater tourist attraction.

Website Layout Example - Analog Mission

Analogs Database
@ Johnson Space Center, Houston, Texas

Text Search the Database
+ Advanced Search

+ Analogs Home	+ Analogs DB	+ Submit Entry	+ Feedback	+ What's New	+ Logout
+ Projects	+ Missions	+ Sites	+ Facilities	+ Equipment	+ Contacts

Mission Details

Name

Advanced Space Suit Field Test 2000

Dates

September 2, 2000 to September 15, 2000

Orgainizational lead or sponsor

NASA JSC

Lead Person

Joseph J. Kosmo

Contact Person

Amy Ross

Description

Until the ASRO project, little was known about the investigation strategies necessary for determining and coordinating the interaction between humans and robotic rover vehicle systems towards achieving effective planetary surface exploration. As a result of this test experience and based on the preliminary findings and recommendations, as reported in CTSD-ADV-360 document, a series of representative planetary surface EVA deployment task were conducted as part of a joint project between elements of NASA-JSC to continue further investigation regarding synergism and interaction between humans and a robotic assistant vehicle for potential future planetary surface exploration application.

Objectives

The objectives of this series of test activities was to develop an interdisciplinary level of "lessons learned" by conducting preliminary engineering assessments and human factor evaluations of various representative space suited EVA / robotic assistant vehicle planetary surface deployment task while in Lunar / mars analogy remote field site locations. In addition, the test activities were valuable in demonstrating to various levels of NASA management, the scope of technology needs that will be required to successfully accomplish future human and robotic assisted rover vehicle exploration of planetary surfaces. Other benefits include public education-outreach opportunities and Public Affairs Office (PAO) coverage for new releases.

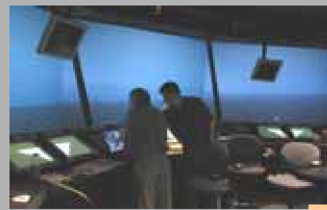
Results

No information in the database.

Lessons Learned

Integrated Analogue Studies - Prerequisites for Human Exploration

Haughton-Mars 1



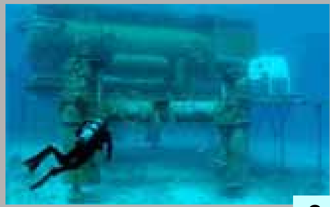
H. Remote Science 2

Desert RATS 3

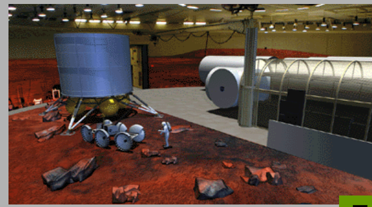
Mars Desert R. S. 4

Flashline Arctic R.S. 5

Elements (○ low, ● high)	Analogue Field Studies									
	1	2	3	4	5	6	7	8	9	10
Science Value	●	◒	◒	◒	●	◒	○	◒	◒	●
Science Operations	●	●	●	●	●	●	◒	◒	◒	◒
Tech. Development	●	●	●	◒	●	◒	●	◒	●	●
Tech. Integration	◒	●	●	◒	◒	◒	●	◒	●	◒
Mission Operations	◒	◒	●	◒	◒	●	●	●	◒	◒
Crew Training/Bio	◒	◒	●	●	●	●	●	●	◒	◒
Human Factors	●	◒	◒	●	●	●	●	●	◒	●
Cost effectiveness	●	●	●	●	◒	●	◒	○	●	●
Outreach/Education	●	●	●	●	●	●	●	●	●	●
Overall Integration	●	●	◒	●	●	◒	●	◒	◒	●



NEEMO 6



Integrity 7

Intl. Space Station 8

Mars Yard/Chamber 9

Antarctic/desert 10

Example Site Characterization Matrix

SITE CHARACTERISTICS

FUNCTIONS	Terrrain									Climate						Science								
	Terrain Type	Slope / Grade	Rock Size Distribution	Soil Properties						Temperature (variation - hi/lo)	Rel Humidity	Precipitation	Insolation	Wind (vel/dir)	Dust	Layered Sediments	Impact Features	Variety (multiple geologic environs)	Micropaleontology / fossils	Surface ice	Volcanics	Geothermal Activity	Isolation	Hostility
				Gradation	Grain Morphology	Ice Content	Moisture Content	Composition	Mechanical Properties															
Human Factors	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW	MED	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW	HI	HI
EMU Testing	HI	HI	HI	MED	MED	MED	HI	MED	HI	HI	HI	MED	MED	MED	HI	MED	MED	MED	MED	MED	MED	MED	LOW	LOW
Ancillary EVA Systems Testing	HI	HI	HI	MED	MED	MED	MED	MED	HI	HI	LOW	LOW	LOW	MED	HI	MED	MED	MED	MED	MED	MED	MED	LOW	LOW
Robotics/Rover Testing	HI	HI	HI	HI	HI	HI	HI	HI	HI	HI	MED	MED	MED	MED	HI	MED	MED	MED	MED	MED	MED	MED	LOW	LOW
Operations	MED	MED	MED	LOW	LOW	LOW	LOW	LOW	MED	HI	LOW	HI	HI	MED	HI	MED	MED	MED	MED	MED	MED	MED	HI	HI
System/Science Equip Deployment	HI	HI	HI	MED	MED	MED	HI	MED	HI	HI	LOW	HI	HI	MED	HI	HI	HI	HI	HI	HI	HI	HI	LOW	LOW
Geology Field Training	HI	HI	HI	LOW	LOW	LOW	HI	LOW	MED	LOW	LOW	MED	LOW	LOW	HI	HI	HI	HI	HI	HI	HI	HI	LOW	LOW
Simulated Traverses	HI	HI	HI	LOW	LOW	LOW	HI	LOW	HI	MED	LOW	MED	LOW	LOW	MED	MED	MED	MED	MED	MED	MED	MED	HI	HI

IMPORTANCE

HI (green) MED (yellow) LOW (red)

HI - high degree of similarity is critical to effective analogy
MED - similarity enhances analogy but is not critical
LOW - similarity not important to effective analogy

OSEWG Lunar Data Synthesis and Integration

- Lunar Reconnaissance Orbiter will provide data that are necessary to develop the maps needed for our return to the moon
  - Launch October 28, 2008
  - Data return will begin soon after start of nominal mission
  - Data will reside in the Planetary Data System, a repository for science data
  - Data in PDS format is not likely to be the most useful form for the users in Exploration Systems
- We need to identify the primary users and their needs
  - Who are the users?
  - What lunar mapping information do they need?
  - What form does the information need to take?
  - When is the information needed?

Lunar Mapping Workshops

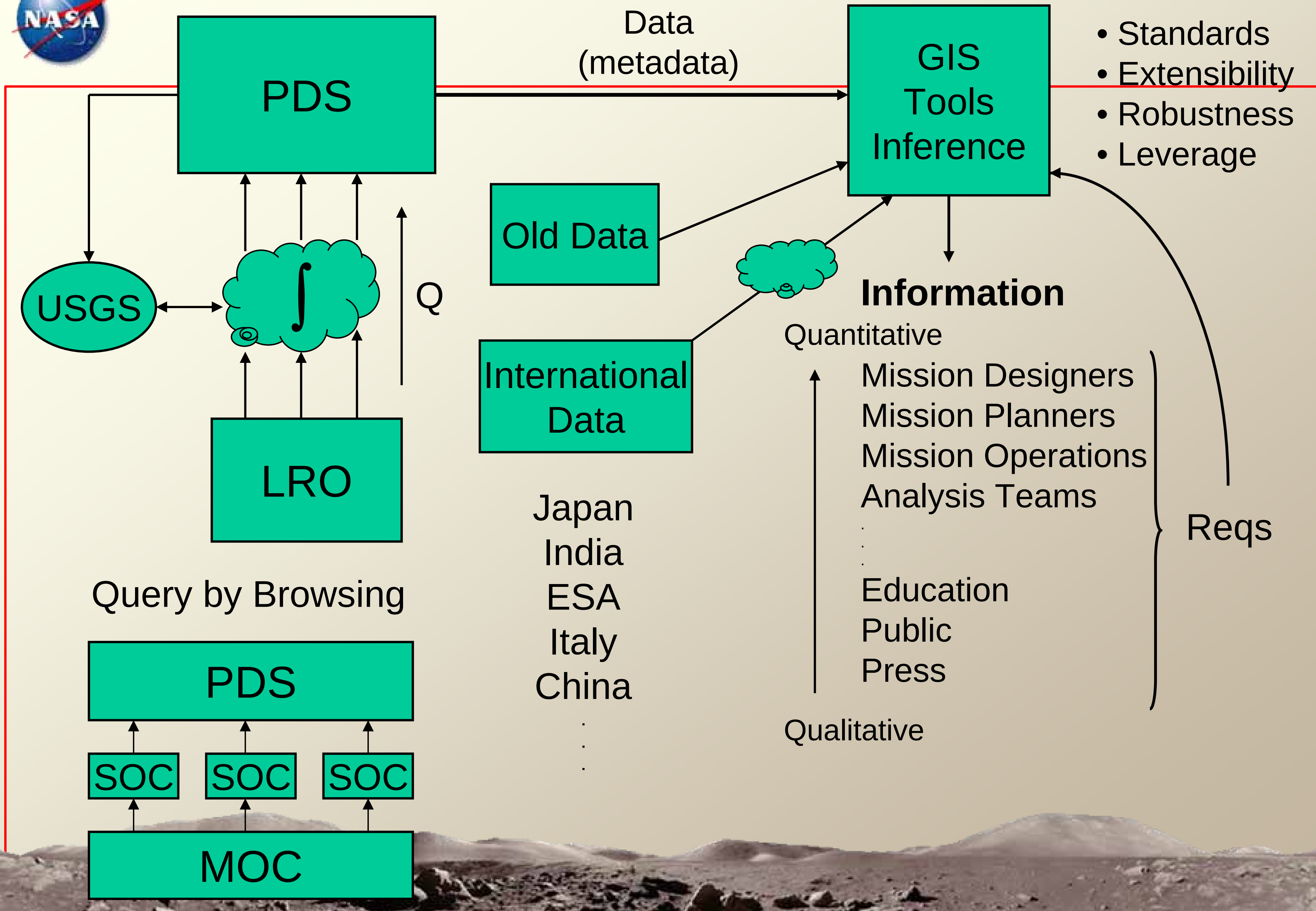
- First workshop dealt with the Why and the What - early activity focused on LRO
- The How is a subject being dealt with in parallel: the lunar mapping architecture

- Who - primary users
  - Constellation
  - LSAM
  - Habitat
  - Mobility
  - Power
  - Surface Ops
  - Site Selection
  - Comm
  - Mobility
  - Lunar Model Dev

- Who - Secondary (for now) users
  - Science
  - Education
  - Public Outreach
  - Public Affairs

Lunar Data Synthesis - Guiding Principles

- Requirements driven
  - Identify users
  - Discriminate between requirements and desirements
- Standards based
- Identify and leverage existing capabilities
- Extensibility
- Robustness


PDS
Data
(metadata)
GIS
Tools
Inference
• Standards
• Extensibility
• Robustness
• Leverage
Old Data
USGS
∫
Q
Information
Quantitative
Mission Designers
Mission Planners
Mission Operations
Analysis Teams
Education
Public
Press
Qualitative
Reqs
International
Data
LRO
Japan
India
ESA
Italy
China
Query by Browsing
PDS
SOC
SOC
SOC
MOC

Backup

Rating Scale Definitions

	○	◔	◑	●
Science Value	None/Not appropriate	Simulated science tasks or science tasks not relevant to planetary science. Little/no publishable results.	Valid scientific objectives/tasks relevant to future planetary exploration. No intent to publish science results or publishible science results not directly relevant to planetary science.	Planetary science tasks lead to publishable (peer-reviewed) science results.
Science Operations	Science operations not relevant to future missions.	Low fidelity relevant science operations, but not focused on operations lessons learned.	Medium fidelity to actual projected science procedures for planetary surface missions. Qualitative lessons learned.	High fidelity of science planning, procedures, communications, and reporting to planetary surface missions. Quantitative metrics.
Technology Development	Little/no technology development	Relevant technology used but not developed. Primarily application of existing technology.	Relevant technology developed but not dependent on analog environment.	New technology tested by taking full advantage of analog environment.
Technology Integration	None/Not appropriate	Different systems used simultaneously but not integrated.	Only a small number of applicable technologies used in an integrated fashion.	Multiple technologies used in an integrated fashion as proposed for actual mission.
Mission Operations	Mission operations not relevant to future missions.	Low fidelity relevant mission operations, but not focused on operations lessons learned.	Medium fidelity to actual projected mission operations for planetary surface missions. Qualitative lessons learned.	High fidelity of mission planning, procedures, communications, and reporting to planetary surface missions. Quantitative metrics.
Crew/Team Training	None/Not appropriate	Tasks developed to meet immediate needs of test. Some applicability to flight or ground crew training.	Tasks are representative of space mission. Alternative procedures are tested and compared.	Tasks are directly applicable to mission preparation for flight or ground crews, e.g. motion flight simulators.
Human Factors	None/Not appropriate	Human crews involved, but low fidelity to planetary habitats or surface activities.	Medium fidelity habitat or surface simulation.	High fidelity habitat or surface simulation.
Medicine/Physiology	None/Not appropriate	Some studies relevant to future long-term human missions	Studies relevant to maintaining crew medical and health for orbital, transit, and/or surface human missions	Direct medical and physiological experiments on humans in long-duration space flight conditions
Outreach/Education	None/Not appropriate	Low level of activity. Low visual content/difficult to explain. Not directly relevant to mission.	Moderate level of activity. Moderate visual content/relatively easy to explain. Partially relevant to mission	High level of activity. High visual content/easy to explain. Directly relevant to mission.
Overall Integration	None/Not appropriate	Low level of overall coordination among analog element (science value, science operations, etc.)	Moderate level of overall coordination among analog element (science value, science operations, etc.)	High level of overall coordination among analog elements (science value, science operations, etc.)

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