LRO Mission Concept of Operations Summary

Version 1.0 (Preliminary)

April - 2005

Goals for ConOps Package

Capture operation concepts for both orbiter and ground systems

- Concepts are documented in the LRO Mission Concept of Operations (431-PLAN-000052)
  - Early Draft is expected to be released at the end of April 2005
  - First official draft release – June 2005
  - Final release prior to Mission CDR
- Once the ConOps document is released, the package will be kept current with each new update to the document

Define mission phases and possible system states

- Concepts will identify initial activities for each mission phase
- Develop high level time-lines for each phase

Package will also identify additional mission activities desired for each phase

Notes for Concept of Operations Package

For each mission sub-phase, activities will be broken into space and ground segment.

- Ground segment is ground assets that support the orbiter after launch
- Space segment is any items that launched by the launch vehicle and GSE required to support those items

TBD/TBR/Action Items List

No.	TBD/TDR/Actions	Slide/Phase	Expected Close Date
1	Verify GSE configuration, do we need command encryption at the launch site?	Launch & Lunar Transfer	
2	Check with propulsion, verify state of ISO valve prior to launch	Launch & Lunar Transfer	
3	Discuss the need for CatBed heaters for potential de-spin. Are they needed based on thermal analysis? If so, do we activate them prior to liftoff?	Launch & Lunar Transfer	
4	Develop required launch window constraints	Launch & Ascent	
5	Update ascent time, either 45 minutes or 20 minutes	Launch & Ascent	
6	C&DH S/W Boot mode, does it exist	Launch & Ascent	
7	For each configuration table, resolve TBRs and add items after design as mature	All Phases	
8	Update De-spin after trade (thruster vs. Yo-Yo)	Separation & De-Spin	
9	Update time duration for De-Spin, Deployment, and Sun Acq.	De-Spin & Sun Acq.	
10	Update after orbiter spin rate is finalized after Sun Acq.	Sun Acq.	
11	Update initial acq. procedure levels	Deployment and Sun Acq.	
12	Update details on commissioning orbit after analysis is complete	LOI	
13	Capture additional details on instrument observations	Routine Ops	
14	Capture additional details on possible instrument calibrations	Routine Ops	

TBD/TBR/Action Items List

No.	TBD/TDR	Slide/Phase	Expected Close Date
15	Both CRaTER and LEND indicated a desire to be powered during Lunar Cruise. Need to analysis if this is possible and data can be recovered.	Lunar Cruise	

LRO Mission Phases Definitions

LRO Mission Phases are broken down into six main phases covering from pre-launch to end-of-mission activities

Each main phase may have several sub-phases

For each main and sub-phase, a start and end points are identified

- If known, an approximate time from launch is provided

LRO Mission Phase Definition Table

No.	Phase	Sub-Phases	Description
1.0	Pre-Launch/Launch Readiness	1.1 Space Segment Readiness 1.2 Ground Segment Readiness	Includes instrument I&T, spacecraft/orbiter I&T, space/ground segment testing as well as operations preparation and ground readiness testing leading up to launch.
2.0	Launch & Lunar Transfer	2.1 Launch and Ascent 2.2 Separation and De-spin 2.3 Deployment and Sun Acq. 2.4 Lunar Cruise 2.5 Lunar Orbit Insertion	Includes all activities & operations from launch countdown sequence to Lunar Orbit Insertion (LOI). LOI includes all maneuvers necessary to obtain the temporary parking orbit for Orbiter activation and commissioning. During the cruise phase, initial spacecraft checkout will be performed to support activities for MCC and LOI.
3.0	Orbiter Activation / Commissioning	3.1 Spacecraft Act. / Commissioning 3.2 Integrated Instrument Act. / Commissioning	Configure and checkout the spacecraft subsystems and ground systems prior to instrument turn-on. Instrument integrated activation will be developed to complete instruments turn-on and commissioning. Instrument commissioning includes any calibration activities needed in the temporary orbit.
4.0	Science Operations	4.1 Measurements (Routine Ops) 4.2 Station-keeping 4.3 Lunar Eclipse 4.4 Yaw Maneuver 4.5 Safehold	One year of nominal science collection in the 50 (+/- 20) km orbit.
5.0	Extended Mission Operations		After 1-year of science observations, orbiter will be boasted into a higher orbit to reduce maintenance requirements. Main purpose for extended mission operations is to perform relay comm. operations. Additional science operations may be performed.
6.0	End-of-Mission Disposal		Includes planning and execution of end-of-life operations. Could include controlled/uncontrolled impact on the Lunar surface.

LRO Mission Phases Start/End Points

No.	Phase		Sub-Phases	Start Point	End Point
1.0	Pre-Launch/Launch Readiness				Start of the launch vehicle countdown sequence at KSC. **(~L-24 hrs)**
2.0	Launch and Lunar Transfer	2.1	Launch and Ascent	Start of the launch vehicle countdown sequence at KSC, approximately L-24 hrs.	Start of payload separation from the launch vehicle third stage. Spacecraft detects separation signal from the launch vehicle, approximately L+30 minutes (Short Coast) or L+45 minutes (Long Coast)
		2.2	Orbiter Separation and De-Spin	Orbiter detection of payload separation from rocket third stage.	Orbiter has de-spin to desired body rates, approximately Separation + 10 minutes
		2.3	Deployment and Sun Acquisition	Orbiter body rates are at De-Spin exit criteria.	Orbiter solar array is deployed and acquired the Sun (Power Positive), approximately Separation + 25 minutes.
		2.4	Lunar Cruise	Orbiter has acquired the Sun and is power positive.	Start of the first Lunar Orbit Insertion burn, approximately L+4 days
		2.5	Lunar Orbit Insertion (LOI)	Start of first LOI burn	Insertion into the spacecraft/instrument commissioning orbit, approximately L+7 days
3.0	Orbiter Activation and Commissioning	3.1	Spacecraft activation and commissioning	Insertion into the activation/commissioning orbit.	Completed spacecraft activation/commissioning. Bus can provide full instrument resources, approximately L+21 days
		3.2	Instruments activation and commissioning	Completion of spacecraft activation/commissioning.	Instrument activated and operating in normal data collection mode. Orbiter is in final mission orbit, approximately L+42 days

LRO Mission Phases Start/End Points

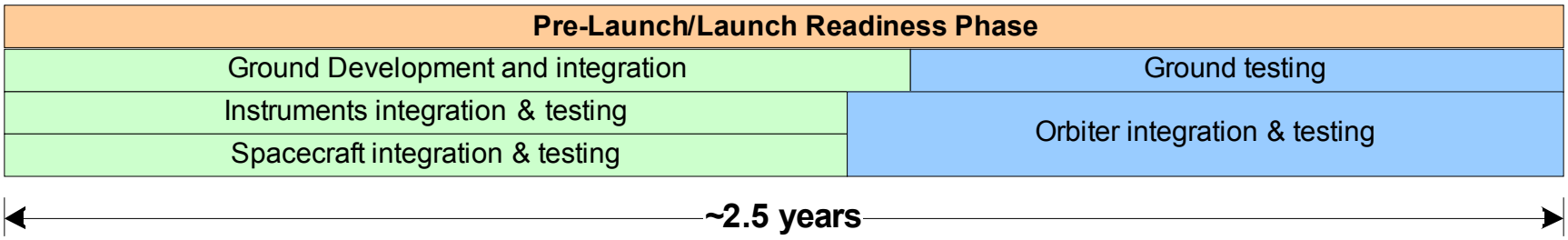
No.	Phase		Sub-Phases	Start Point	End Point
4.0	Routine Operations	4.1	Measurement Operations	End of instrument commissioning, instrument calibrations are completed for initial checkout, approximately L+ 42 days.	Approximately 1 year after start of routine measurement operations, approximately L+407 days.
		4.2	Orbit Maintenance and Calibrations	Performed monthly	Requires 1 day for all activities, actual end point will vary on number of activities
		4.3	Lunar Eclipse	Start configuring the orbiter for Lunar Eclipse	End of Lunar Eclipse and return orbiter to nominal configuration.
		4.4	Yaw Maneuver	Start of maneuver for 180 degree Yaw Maneuver	Completion of maneuver and return the orbiter to nominal operating mode
		4.5	Safehold	Following safing action that results placing the orbiter into safehold	After initial problem is resolved and the ground re-configures the orbiter for nominal operations
5.0	Extended Mission Operations			Approximately 1-year after start of nominal measurement operations	Completion of extended mission objectives or disposal resource allocations are reached
6.0	End-of-Mission			End of extended mission operations or disposal resource allocations are reached.	Completion of all end-of-mission disposal activities and mission closeout activities.

1.0 Pre-Launch/Launch Readiness

Pre-Launch/Launch Readiness Phase includes activities during orbiter integration and test (I&T) and ground system I&T. The start point of this phase correspond to the start of orbiter I&T and ground system I&T. The phase continues until the start of the launch vehicle countdown sequence (Approximately L-24 to 18 hours). This phase includes two sub-phases, Space Segment Readiness and Ground Segment Readiness.

Space Segment Readiness sub-phase includes all orbiter activities associated with preparing the orbiter for launch. This includes necessary ground support equipment to support the activities.

Ground Segment Readiness sub-phase includes all ground system activities associated with preparing the LRO ground system for launch and normal operations.



1.1 Space Segment Launch Readiness

Space Segment Readiness Definition

- Ground Support Equipment (GSE) development & testing
- Integration of spacecraft and instruments
  - Safe-to-mate, interface checks, functional checks
- Orbiter level functional and performance tests
- Orbiter level environmental testing
  - Vibration, Acoustics, Thermal Vac/Balance, EMI/EMC
  - Orientation for thermal vacuum testing shall be the X and Y axis forming the horizontal plane +/-0.1 inch/2 meters in length
    - » All faces of the orbiter shall have clear fields of view to cryopanel and/or heater plate and/or cal rod arrays
- Support ground system and operations testing
- Ship to launch site
- Launch site processing
  - Post-ship functional/checkout
  - Propulsion system fueling and balance
  - Safe-to-mate with launch vehicle
  - Launch vehicle interface tests and rehearsals
  - Launch site interface tests with ground segment
  - Launch vehicle payload section integration to launch vehicle
  - Fairing close-outs
  - Battery monitoring/conditioning
  - Instrument and fairing purging

1.2 Ground Segment Launch Readiness

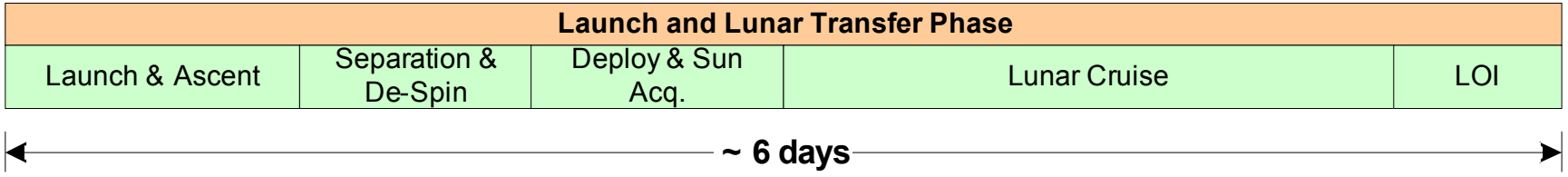
Ground Segment Launch Readiness Definition

- Ground software development/releases
  - Three separate software releases
- Ground system integration and test
- Ground system verification testing
  - Mission readiness testing (MRT), verify level 3 requirements
  - Minimum of 5 MRT tests
- Operations Development
  - Flight Operations plan
  - Flight Procedures
  - Mission Time-lines
  - Mission telemetry & command databases
  - Operations training
- Operations Testing
  - Mission Rehearsals (cover all phases of the mission)
  - Mission simulations using either orbiter or high fidelity simulator
  - Operations products testing and verification
  - Operations readiness testing (ground system proficiency testing)

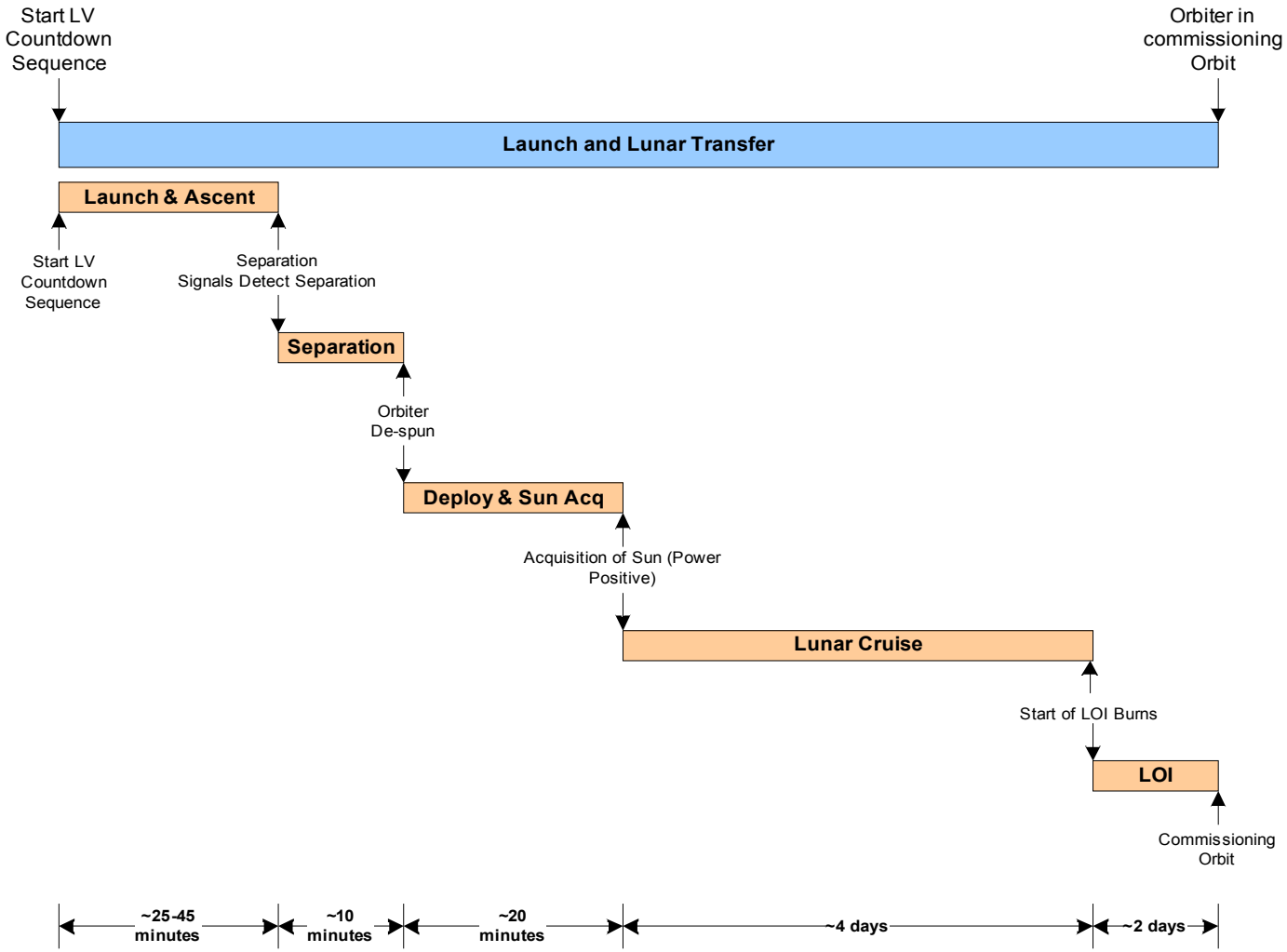
2.0 Launch and Lunar Transfer

The launch and Lunar Transfer phase starts when the launch vehicle countdown sequence is initiated at KSC. The launch countdown sequence typically starts between L-24 hrs and L-18 hrs. The final activity in this phase is the series of Lunar Orbit Insertion (LOI) burns to capture into the commissioning orbit. Sub-Phases are:

2.1 Launch and Ascent
2.2 Separation (from launch vehicle third stage)
2.3 Deployment and Sun Acquisition
2.4 Lunar Cruise
2.5 Lunar Orbit Insertion



2.0 Launch and Lunar Transfer Timeline



2.1 Launch and Ascent

Launch and Lunar Transfer Phase				
Launch & Ascent	Separation & De-Spin	Deploy & Sun Acq.	Lunar Cruise	LOI

Launch and Ascent sub-phase starts at the beginning of the launch vehicle countdown sequence

- Pre-plan sequence developed by the launch vehicle/KSC team
- Sequence is used for rehearsals during launch readiness phase

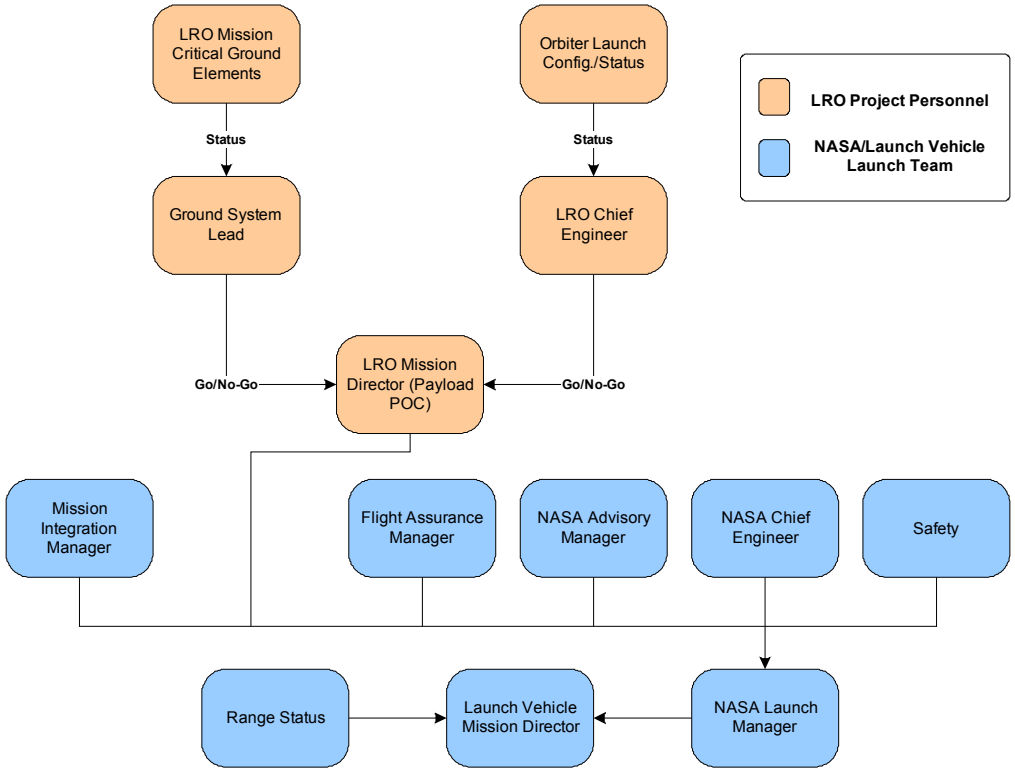
Launch Window Constraints (TBR)

- Require sun availability for initial sun acquisition (Don't separate and de-spin in eclipse)?
- Possible constraints if LOI is near Beta angle 0 degrees?

Mission Level Activities

- LRO Project/engineering team will be split, small group located at KSC for launch activities. Remaining team will be located at the GSFC Mission Operations Center (MOC).
- LRO GSE will be connected to the orbiter through hard-line LV interface
  - LRO Launch team will use this interface to power and configure the orbiter for launch
  - While the orbiter is powered on the pad, the telemetry is relayed back to the MOC at GSFC for the remaining project/engineering team.
- At approximately L-18 hrs, the launch vehicle countdown sequence begins
  - Space and ground segment teams configure and verify systems prior to launch

2.1 Launch and Ascent Sub-Phase



Notional launch day information flow. Purpose of the information flow is to pass readiness status to project representative at the launch control room

- Ground team verifies ground critical elements
- Launch site team configures and verifies orbiter status prior to launch

Information is pass through the project representative. Polling information is provided during the launch vehicle countdown sequence activities

2.1 Launch and Ascent Sub-Phase

Space Segment Concepts

- KSC project team uses the GSE to power and configure the orbiter into the launch configuration, reference launch configuration table on next slide
- The GSE located at KSC forwards real-time telemetry to the MOC at GSFC
- Need to add activities on third stage activities
- C&DH Activities:
  - Load launch data storage filter table for SBC memory recorder
    - » DS Filter table will record engineering/housekeeping data at 16 kbps rate. Expected storage time is 1.5 hrs (covers long ascent phase, separation, Sun Acq, and small contingency)
  - KSC GSE will use 4 kbps command rate (hard-line) to configure orbiter
  - Orbiter will be configured to output 16 kbps telemetry during the pre-launch period. 16 kbps housekeeping/engineering data will be received by the KSC GSE and forwarded to the MOC at GSFC.
  - Verify separation sequence is active
  - Configure S/W mode to Boot (TBR)?
  - Verify launch separation Relative Time Sequences (RTSs)

2.1 Launch and Ascent Sub-Phase

Space Segment Concepts (Continue)

- Power Activities:
  - During orbiter configuration, bring battery on-line. Orbiter will switch to internal power approximately 30 minutes before liftoff
  - Verify Battery state of charge
  - Verify power configuration is in launch mode
- Comm. Activities:
  - Configure RF switches for omni operations
- Thermal Activities:
  - Configure thermal control system for launch mode
  - Verify deployment heaters are enabled
  - Verify survival heaters are enabled (both for spacecraft & instruments)
- Propulsion Activities:
  - Verify propulsion configuration for launch mode
  - Question: Verify status of isolation valve and Catbed operations
- GNC Activities:
  - Verify gyro is powered
  - Verify ACS Software mode
  - Verify remaining GNC components are in launch configuration mode
- GSE
  - Runs launch configuration procedure
  - Performs routine commands/telemetry checks prior to liftoff
  - Forwards telemetry to GSFC MOC

2.1 Launch and Ascent Sub-Phase

LRO Orbiter (Space Segment) Launch Configuration (TBR)					
Component/System	**Category**	**Configuration**	**Component/System**	**Category**	**Configuration**
C&DH Box	C&DH	On	LROC	Inst.	Off
Solid State Recorder	C&DH	Off	LOLA	Inst.	Off
C&DH S/W Mode	C&DH	Boot Mode (TBR)	LEND	Inst.	Off
C&DH S/W Config	C&DH	Launch DS filter table	CRaTER	Inst.	Off
R-T Telemetry	C&DH	16 kbps (hardline through LV)	LAMP	Inst.	Off
Cmd Rate	C&DH	4kbps	Diviner	Inst.	Off
Comm. Cards	C&DH	On	Battery	Power	Online
S-Band Receivers	Comm.	On	PSE	Power	On
S/Ka Band Xmitter	Comm.	Off	Servo Drive Bus	Power	Off (TBR)
Transponder Config.	Comm.	RF Switches configured for Omni	Deployment Bus	Power	Off
Reaction Wheels	GNC	Off	Isolation Valve	Prop.	Closed (TBR)
Star Trackers	GNC	Off	Prop. Heaters	Prop.	Enabled
IMU/Gyro	GNC	On	CATBED Heaters	Prop.	Off (TBR)
ACS S/W Mode	GNC	De-spin (TBR)	Prop. Thrusters	Prop.	Off
Survival Heater Bus	Thermal	Enabled	Thermal Pumps?	Thermal	Off
Inst. Survival HTRs	Thermal	Enabled	S/C Ops Heaters	Thermal	Off
Deployment HTRs	Thermal	Enabled	Inst. Ops Heaters	Thermal	Off

2.1 Launch and Ascent Sub-Phase

Ground Segment Concepts

- Operations team staffs the MOC and flight dynamics facilities
- Ground segment executes the ground system countdown sequence
  - Sequence provides a time-line of activities for configuring and verifying systems for launch
    - » Interface checks with ground network (Cmd/Tlm)
    - » Voice comm. configuration/checks
    - » Readiness checks for launch critical facilities such as the MOC and flight dynamics
  - Readiness information is collected and passed to the launch site LRO representative
- Verify initial acq. data is transferred to the ground network
- Receive orbiter real-time housekeeping data from KSC
- Brief the ground network on initial acq. procedures
- Mission Operations Center is staffed by the following teams:
  - Flight Operations Team (FOT)
  - Spacecraft engineering team
  - Instrument engineering team
- Monitor launch vehicle countdown sequence, support engineering team at the launch site
- Configure hardware and software systems for initial acquisition

2.1 Launch and Ascent Sub-Phase

Ground Segment Concept (Continue):

- Preliminary launch critical ground elements
  - Flight Dynamics Facilities – Staffed/Operational
  - Flight Dynamics Analysis Branch – Staffed/operational
  - Mission Operations Center – Staffed/operational
    - » Mandatory systems include ITOS, mission planning and data archiving systems
    - » MOC needs to be staffed by operations team, S/C engineers, and instruments engineers
  - Ground Network – Operational (initial acquisition station)
    - » Functions include uplink/telemetry systems, tracking systems, data distribution systems
  - Networks – Data/Voice networks are operational (Between MOC, FDF, FDAB, and ground networks are mandatory)

2.1 Launch and Ascent

Mission Activity Summary for Launch & Ascent Sub-Phase					
Activity	**Affected System**	**Performed By**	**Activity**	**Affected System**	**Performed By**
Launch Vehicle Countdown Sequence	All	LV Team	Ground segment launch countdown sequence	All Ground	Grnd Team
Configure Orbiter to launch mode	Orbiter	GSE	Staff/configure MOC	MOC	FOT
Monitor orbiter status prior to launch	Orbiter	LRO Launch Team	Staff/Configure FDF/FDAB	FD	FD Teams
Forward 16 kbps telemetry to MOC	GSE	GSE	Receive 16 kbps from KSC	ITOS	Launch site GSE
			Monitor ground element status	All Ground	Grnd Team

2.2 Separation & De-Spin Sub-Phase

Launch and Lunar Transfer Phase				
Launch & Ascent	Separation & De-Spin	Deploy & Sun Acq.	Lunar Cruise	LOI

The separation & de-spin sub-phases begins when the orbiter detects launch vehicle separation. The sub-phase ends when the orbiter is de-spun to within the desired rate ranges.

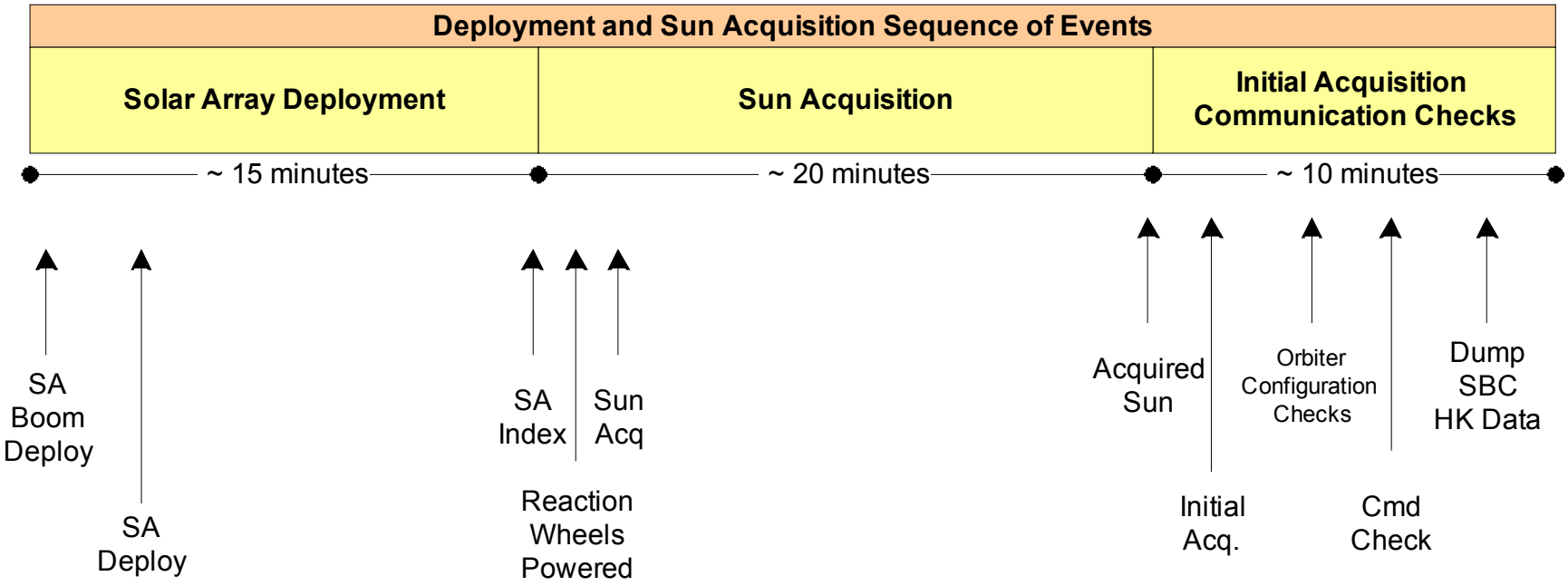
Prior to separation, the orbiter remains in the launch configuration mode

Mission Activities:

- Activities performed by the orbiter is executed through the separation sequence. The orbiter performs separation activities without ground intervention.
- The separation sequence controls orbiter activities through Sun Acquisition

2.2 Separation & De-Spin Sub-Phase

Separation & De-Spin Sequence of Events



2.2 Separation & De-Spin Sub-Phase

Space Segment Concept

- The launch vehicle will have three separation signals that the orbiter monitors
  - Separation is determined when 2 of the 3 signals indicate separation
  - Indication of separation will start the separation sequence
- Orbiter does not transmit any telemetry during this phase
- C&DH Activities:
  - Monitors separation signals, once separation is detected, C&DH will start the separation sequence
  - Orbiter housekeeping/engineering telemetry continues to be stored using the SBC memory
- GNC Activities:
  - Separation sequence verifies/configures the orbiter for De-Spin
  - GNC monitors spin rate using the gyro, de-spin is complete once orbiter spin rate is reduced to TBR rates. Spin rate should be faster than LROC sun avoidance requirement. De-spin should take less than 10 minutes (TBR) from separation detection.

2.2 Separation & De-Spin Sub-Phase

LRO Orbiter (Space Segment) Separation & De-Spin Configuration (TBR)					
Component/System	**Category**	**Configuration**	**Component/System**	**Category**	**Configuration**
C&DH Box	C&DH	On	LROC	Inst.	Off
Solid State Recorder	C&DH	Off	LOLA	Inst.	Off
C&DH S/W Mode	C&DH	Boot Mode (TBR)	LEND	Inst.	Off
C&DH S/W Config	C&DH	Launch DS filter table	CRaTER	Inst.	Off
R-T Telemetry	C&DH	Off	LAMP	Inst.	Off
Cmd Rate	C&DH	N/A	Diviner	Inst.	Off
Comm. Cards	C&DH	On	Battery	Power	Online (Discharging)
S-Band Receivers	Comm.	On	PSE	Power	On
S Band Xmitter	Comm.	Off	Servo Drive Bus	Power	Off (TBR)
Ka Band Xmitter	Comm.	Off	Deployment Bus	Power	Off
Transponder Config.	Comm.	RF Switches configured for Omni	Isolation Valve	Prop.	Open
Reaction Wheels	GNC	Off	Prop. Heaters	Prop.	Enabled
Star Trackers	GNC	Off	CATBED Heaters	Prop.	Off (TBR)
IMU/Gyro	GNC	On	Prop. Thrusters (TBR)	Prop.	Off
ACS S/W Mode	GNC	De-spin	Thermal Pumps?	Thermal	Off
Survival Heater Bus	Thermal	Enabled	S/C Ops Heaters	Thermal	Off
Inst. Survival HTRs	Thermal	Enabled	Inst. Ops Heaters	Thermal	Off
Deployment HTRs	Thermal	Enabled			

2.2 Separation & De-Spin Sub-Phase

Ground Segment Concept

- Ground system elements are in stand-by mode, awaiting initial acquisition
- Following separation, flight dynamics receives the separation vector from the launch vehicle team
  - Vector is usually faxed to flight dynamics
  - Flight dynamics use the vector to compare launch vehicle insertion errors
- MOC will configure with initial acquisition station and perform command/telemetry checks with ground site
- Ground site will use nominal acq. data for initial acquisition. Ground site will also have initial acq. contingency procedures ready

2.2 Separation & De-Spin Sub-Phase

Mission Activity Summary for Separation & De-Spin Sub-Phase					
Activity	**Affected System**	**Performed By**	**Activity**	**Affected System**	**Performed By**
Orbiter detects LV separation state	Orbiter	C&DH S/W?	Ground Network prepares for Initial Acquisition	Grnd Network	Grnd
Start separation sequence script	Orbiter	C&DH S/W	Verify MOC ITOS systems and engineering system connections	Grnd	MOC
Store orbiter HK data	C&DH	C&DH S/W			
Orbiter enters de-spin mode	GNC	Sep. Seq.			
De-spin orbiter to TBR rates	GNC	ACS S/W			
Configure propulsion system for de-spin	Propulsion	Sep. Seq.			

2.3 Deployment and Sun Acquisition Sub-Phase

Launch and Lunar Transfer Phase				
Launch & Ascent	Separation & De-Spin	Deploy & Sun Acq.	Lunar Cruise	LOI

Sub-Phase starts after orbiter has de-spun to desired rates and ends once the orbiter has acquired the sun and is power positive.

Mission Activities:

- Solar Array deployment
- Indexing the solar array position
- Configuring GNC components for sun acquisition
- Maneuvering the orbiter to acquire the sun (Power Positive)
- Ground Initial Acquisition
- Verify orbiter telemetry at the MOC

2.3 Deployment and Sun Acquisition Sub-Phase

Space Segment Concept

- Using the separation sequence, the sequence will perform the following activities:
  - Deploy the solar arrays (perform at least two attempts)
  - Index the solar arrays
  - Power the reaction wheels and place the ACS software in sun acquisition
- C&DH Activities:
  - Continue to execute the separation sequence
  - Collect/store housekeeping data using the SBC board memory
- Power Activities:
  - Deploy the solar arrays and command array to safehold index
    - » Expected time for solar array deployment is 15 minutes (TBR)
- GNC Activities:
  - After deployment, reaction wheels are powered
  - ACS Software is placed in the sun acquisition mode. Using wheels, the orbiter will acquire the sun. It is expected that sun acquisition will take approximately 20 minutes (TBR).
  - After sun acquisition, the Solar Array (SA) boresite will be +/- 20° from the sun line
  - Orbiter will spin ~0.1°/sec (TBR)

2.3 Deployment and Sun Acquisition Sub-Phase

Space Segment Concept (Continue):

- Initial Acquisition Procedures:
  - Following sun acquisition, the separation sequence will configure the orbiter for initial acquisition.
  - Separation sequence monitors receiver signal strength, if receiver signal strength is greater than -95 dBm (TBR), the sequence will command the S-Band transmitters on at the 16 kbps rate using the omni.
  - After TBD time, the sequence will enter pulse mode where is turns the S-Band transmitter on for short periods to aid the ground station search pattern.

2.3 Deployment and Sun Acquisition Sub-Phase

LRO Orbiter (Space Segment) Deployment and Sun Acquisition Configuration (TBR)					
Component/System	**Category**	**Configuration**	**Component/System**	**Category**	**Configuration**
C&DH Box	C&DH	On	LROC	Inst.	Off
Solid State Recorder	C&DH	Off	LOLA	Inst.	Off
C&DH S/W Mode	C&DH	Boot Mode (TBR)	LEND	Inst.	Off
C&DH S/W Config	C&DH	Launch DS filter table	CRaTER	Inst.	Off
R-T Telemetry	C&DH	16 kbps	LAMP	Inst.	Off
Cmd Rate	C&DH	4 kbps	Diviner	Inst.	Off
Comm. Cards	C&DH	On	Battery	Power	Online (Charging)
S-Band Receivers	Comm.	On	PSE	Power	On
S Band Xmitter	Comm.	On	Servo Drive Bus	Power	On
Ka Band Xmitter	Comm.	Off	Deployment Bus	Power	On
Transponder Config.	Comm.	RF Switches configured for Omni	Isolation Valve	Prop.	Open
Reaction Wheels	GNC	Off	Prop. Heaters	Prop.	Enabled
Star Trackers	GNC	Off	CATBED Heaters	Prop.	Off
IMU/Gyro	GNC	On	Prop. Thrusters (TBR)	Prop.	Off
ACS S/W Mode	GNC	De-spin	Thermal Pumps?	Thermal	Off
Survival Heater Bus	Thermal	Enabled	S/C Ops Heaters	Thermal	Off
Inst. Survival HTRs	Thermal	Enabled	Inst. Ops Heaters	Thermal	Off
Deployment HTRs	Thermal	Enabled			

2.3 Deployment and Sun Acquisition Sub-Phase

Ground Segment Concept:

- Ground Network:
  - Ground site will perform initial acquisition based on nominal predicts
    - » After TBD time, contingency search patterns will be executed
    - » Ground site will be configured for 16 kbps real-time telemetry and 4 kbps command uplink
    - » Initial acquisition procedures will be directed by the LRO operations team
- MOC:
  - After initial acquisition, real-time telemetry (16 kbps) is received at the MOC.
    - » MOC teams will monitor and evaluated orbiter health
  - FOT will perform command checks using command encryption
  - Orbiter configuration checks are executed using ITOS
  - Orbiter real-time 16 kbps data is forwarded to KSC GSE for launch site team
- Flight Dynamics
  - Start processing tracking data from ground network
  - Based on errors, re-issue acq and planning products

2.3 Deployment and Sun Acquisition Sub-Phase

Mission Activity Summary for Deployment and Sun Acquisition Sub-Phase					
Activity	**Affected System**	**Performed By**	**Activity**	**Affected System**	**Performed By**
Configure for Solar Array Deployment	Power, C&DH	Separation Sequence	Perform initial acquisition	Grnd	Ground Network
Deploy Solar Array, multiple attempts	Power, C&DH	Separation Sequence	Verify 16kbps telemetry rate after initial acq.	Grnd	MOC
Configure ACS Software for Sun Acquisition mode	Power, C&DH, GNC	Separation Sequence	Send test commands	Grnd, Orbiter	MOC
Acquire Sun	Power, GNC	ACS S/W	Orbiter configuration checks	Grnd	MOC
Configure spacecraft for initial acquisition with ground	System	Separation Sequence	Forward 16kbps real-time telemetry to KSC	Grnd	MOC
Power on reaction wheels	Power, GNC	Separation Sequence	Receive LV separation vector from launch vehicle team	FD	LV Team
			Verify power positive condition	Orbiter	MOC
			Change telemetry data rate to 300 kbps	Comm, C&DH, Grnd	MOC
			Dump SBC stored engineering data	Comm, C&DH, Grnd	MOC, C&DH S/W

2.4 Lunar Cruise Sub-Phase

Launch and Lunar Transfer Phase				
Launch & Ascent	Separation & De-Spin	Deploy & Sun Acq.	Lunar Cruise	LOI

Sub-Phase starts after orbiter has deployed the solar arrays and acquired the Sun.

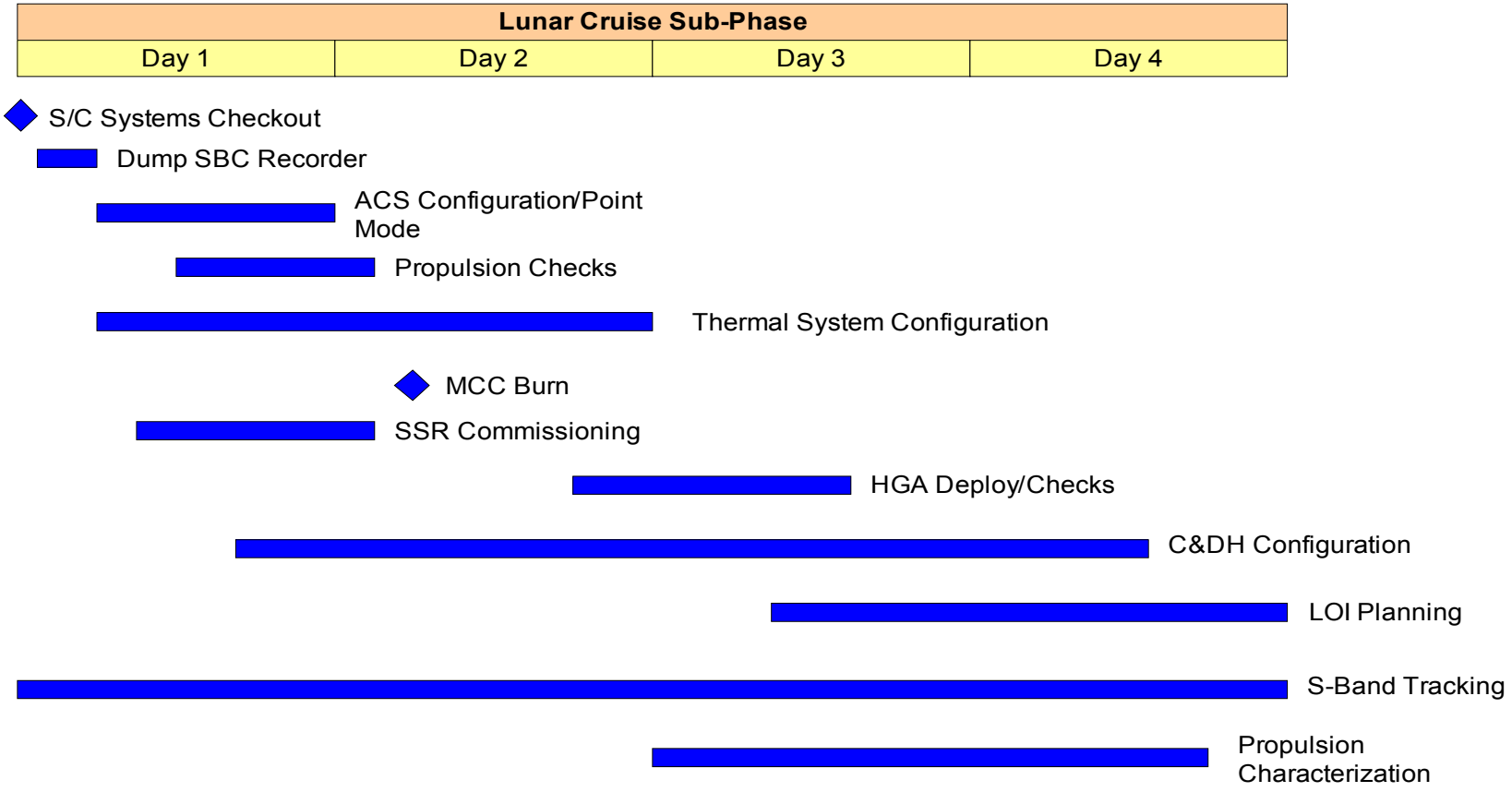
- Orbiter should be power positive and dumping the stored engineering data from the SBC memory.

Mission Activities:

- Collect Doppler and range data for MCC maneuver
- Configure GNC and propulsion for MCC maneuver
- Start initial spacecraft activation sequence
- Perform ground network checks

2.4 Lunar Cruise Sub-Phase

Lunar Cruise Sequence of Events



2.4 Lunar Cruise Sub-Phase

Space Segment Concepts:

- C&DH:
  - Commissioning SSR
  - Transitioning software to nominal mode
  - Configuring safing software
  - Verify CFDP processing
- Power:
  - Configuring power parameters
  - Enable servo drive bus and electronics
- Propulsion:
  - Configure propulsion system for maneuvers
  - Perform MCC maneuver
  - Characterize propulsion system prior to LOI
- GNC
  - Transition ACS to point mode
  - Commission star trackers
  - Characterize ACS performance
- Comm.
  - Deploy HGA
  - Verify S/Ka data rates
  - Verify different command rates
- Thermal
  - Enable operational heaters
  - Configure heater control system for increasing loads

2.4 Lunar Cruise Sub-Phase

LRO Orbiter (Space Segment) Lunar Cruise Configuration (TBR)					
Component/System	**Category**	**Configuration**	**Component/System**	**Category**	**Configuration**
C&DH Box	C&DH	On	LROC	Inst.	Off (Contam. HTRs On?)
Solid State Recorder	C&DH	On	LOLA	Inst.	Off
C&DH S/W Mode	C&DH	Normal Mode (TBR)	LEND	Inst.	Off
C&DH S/W Config	C&DH	Nominal Config.	CRaTER	Inst.	Off
R-T Telemetry	C&DH	16 kbps (Nominal)	LAMP	Inst.	Off (Contam. HTRs On?)
Cmd Rate	C&DH	4 kbps (Nominal)	Diviner	Inst.	Off
Comm. Cards	C&DH	On	Battery	Power	Online (Charging)
S-Band Receivers	Comm.	On	PSE	Power	On
S Band Xmitter	Comm.	On	Servo Drive Bus	Power	On
Ka Band Xmitter	Comm.	Cycle	Deployment Bus	Power	On
Transponder Config.	Comm.	RF Switches configured for Omni	Isolation Valve	Prop.	Open
Reaction Wheels	GNC	On	Prop. Heaters	Prop.	Enabled
Star Trackers	GNC	On	CATBED Heaters	Prop.	Cycle
IMU/Gyro	GNC	On	Prop. Thrusters (TBR)	Prop.	On
ACS S/W Mode	GNC	Point Mode	Thermal Pumps?	Thermal	On
Survival Heater Bus	Thermal	Enabled	S/C Ops Heaters	Thermal	On
Inst. Survival HTRs	Thermal	Enabled	Inst. Ops Heaters	Thermal	Off
Deployment HTRs	Thermal	Enabled			

2.4 Lunar Cruise Sub-Phase

Ground Segment Concepts:

- Ground Network:
  - Performing CFDP during Ka-band test passes
  - Supporting various cmd uplink rates
  - Supporting various telemetry D/L rates
  - Forwarding stored engineering data to MOC
  - Passes Real-time telemetry to MOC
  - Performing continuous ranging/Doppler tracking and forwarding to flight dynamics
- MOC
  - Receiving and processing real-time and stored orbiter data
  - Executing the spacecraft commissioning time-line
  - Spacecraft and instrument engineers monitoring orbiter systems at MOC
  - Passes mission planning products to instrument SOCs
  - Track fuel usage
  - Perform trending on selected telemetry points
  - MOC is staffed 24 hrs, prime activities occur during first shift
- Flight dynamics
  - Generate mission products
  - Develop MCC plan
  - Plan and develop LOI plan
  - Ingest and processing tracking data
- Instrument SOCs
  - Supporting mission activities
  - Receiving orbiter housekeeping data

2.4 Lunar Cruise Sub-Phase

Mission Activity Summary for Deployment and Sun Acquisition Sub-Phase					
Activity	**Affected System**	**Performed By**	**Activity**	**Affected System**	**Performed By**
Perform MCC burn	Propulsion, GNC	MOC, C&DH S/W	Orbiter tracking	Ground Network	Ground Network
Deploy HGA	Power, Mech, GNC	MOC	Executing commissioning timeline	Orbiter	MOC
Power Commissioning	Power	MOC	Orbiter telemetry trending	MOC	MOC
C&DH Commissioning	C&DH	MOC	Process tracking data	FD, GN	FD
Thermal Commissioning	Thermal	MOC	Generate mission products	MOC, FD	MOC, FD
Propulsion Commissioning	Propulsion	MOC			
Comm. Commissioning	Comm.	MOC			

2.5 Lunar Orbit Insertion (LOI) Sub-Phase

Launch and Lunar Transfer Phase				
Launch & Ascent	Separation & De-Spin	Deploy & Sun Acq.	Lunar Cruise	LOI

Sub-phase starts at the beginning of the first LOI burn

Mission Activities:

- Perform the series of LOI burns to capture into the commissioning orbit
- Commissioning orbit is 90x110 km
  - ~90° inclination

2.5 Lunar Orbit Insertion (LOI) Sub-Phase

Space Segment Concept:

- Propulsion:
  - Configure propulsion system for LOI burns
  - Series of 3 burns over approx. 2 days to capture into the commissioning orbit
  - Each maneuver involves:
    - » Configuring prop. System (enable CatBed, thrusters, etc)
    - » Pointing S/C
    - » Transition to delta-V mode
    - » Return to 3-Axis point and nominal pointing
- Comm:
  - Since off-point is needed, omni will be used for S-Band
  - Assume nominal 16 kbps rate

2.5 Lunar Orbit Insertion (LOI) Sub-Phase

LRO Orbiter (Space Segment) Lunar Cruise Configuration (TBR)					
Component/System	**Category**	**Configuration**	**Component/System**	**Category**	**Configuration**
C&DH Box	C&DH	On	LROC	Inst.	Off (Contam. HTRs On?)
Solid State Recorder	C&DH	On	LOLA	Inst.	Off
C&DH S/W Mode	C&DH	Normal Mode (TBR)	LEND	Inst.	Off
C&DH S/W Config	C&DH	Nominal Config.	CRaTER	Inst.	Off
R-T Telemetry	C&DH	16 kbps (Nominal)	LAMP	Inst.	Off (Contam. HTRs On?)
Cmd Rate	C&DH	4 kbps (Nominal)	Diviner	Inst.	Off
Comm. Cards	C&DH	On	Battery	Power	Online (Charging)
S-Band Receivers	Comm.	On	PSE	Power	On
S Band Xmitter	Comm.	On	Servo Drive Bus	Power	On
Ka Band Xmitter	Comm.	Cycle	Deployment Bus	Power	Off
Transponder Config.	Comm.	RF Switches configured for Omni/HGA	Isolation Valve	Prop.	Open
Reaction Wheels	GNC	On	Prop. Heaters	Prop.	Enabled
Star Trackers	GNC	On	CATBED Heaters	Prop.	Cycle
IMU/Gyro	GNC	On	Prop. Thrusters (TBR)	Prop.	On
ACS S/W Mode	GNC	Point Mode/Delta-V	Thermal Pumps?	Thermal	On
Survival Heater Bus	Thermal	Enabled	S/C Ops Heaters	Thermal	On
Inst. Survival HTRs	Thermal	Enabled	Inst. Ops Heaters	Thermal	Off
Deployment HTRs	Thermal	Enabled			

2.5 Lunar Orbit Insertion (LOI) Sub-Phase

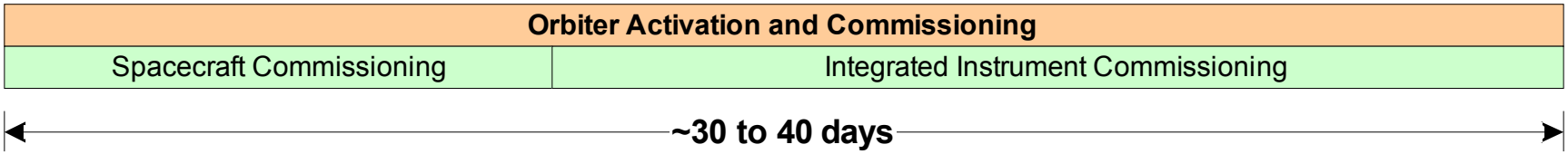
Ground Segment Concept:

- Ground Network
  - Maneuvers may need to be supported by DSN
  - Continuous tracking
- MOC
  - Upload LOI plans and monitor burns
  - Monitor orbiter systems
  - Track fuel usage
  - 24 hour coverage (Staffed)
- Flight Dynamics
  - Plan LOI burns
  - Monitor performance
  - Update mission products
  - Process continuous ranging/Doppler data

3.0 Orbiter Commissioning

The orbiter activation and commissioning phase starts once the orbiter reached the commissioning orbit. The final step in orbiter commissioning is inserting into the final mission orbit of 50 km. A portion of the spacecraft activation sequence is executed during the cruise phase. Sub-Phases are:

3.1 Spacecraft Activation and commissioning
3.2 Integrated Instrument activation and commissioning



3.0 Orbiter Commissioning

Definitions:

- Commissioning includes both activation and cal/val
- During activation, sequence includes powering components and functionally verify systems.
- During Cal/Val, system performance is verified
- Instrument Cal/Val sequence should be defined by the Science Team
- Instrument teams will develop individual Instrument activation sequence and the project will develop the integrated activation sequence.
  - Sequence will minimize the overall time

3.1 Spacecraft Commissioning

Space Spacecraft Commissioning Concept:

- Portion of activities will be performed during cruise sub-phase
- Power
  - Verify power analysis
  - Modify any power parameters
- GNC
  - Operate in point mode with gyro, ST, wheels and KF
  - Monitor SA and HGA operations
  - Maintain Sun Avoidance for instruments
  - Perform ACS calibrations (bias, alignment updates)
- Thermal
  - Configure thermal system
  - Verify heater configurations
- Propulsion
  - Verify/Update thruster efficiency, alignments
- Comm
  - Check Ka system
  - Dump data through S-Band (Ka Contingency)
  - S/Ka link analysis
- C&DH
  - Verify CFDP
  - Enable/Configure safing system

3.1 Spacecraft Commissioning

LRO Orbiter (Space Segment) Spacecraft Commissioning Configuration (TBR)					
Component/System	**Category**	**Configuration**	**Component/System**	**Category**	**Configuration**
C&DH Box	C&DH	On	LROC	Inst.	Off (Contam. HTRs On)
Solid State Recorder	C&DH	On	LOLA	Inst.	Off
C&DH S/W Mode	C&DH	Normal Mode (TBR)	LEND	Inst.	Off
C&DH S/W Config	C&DH	Nominal Config.	CRaTER	Inst.	Off
R-T Telemetry	C&DH	16 kbps (Nominal)	LAMP	Inst.	Off (Contam. HTRs On)
Cmd Rate	C&DH	4 kbps (Nominal)	Diviner	Inst.	Off
Comm. Cards	C&DH	On	Battery	Power	Online (Cycle)
S-Band Receivers	Comm.	On	PSE	Power	On
S Band Xmitter	Comm.	On	Servo Drive Bus	Power	On
Ka Band Xmitter	Comm.	Cycle	Deployment Bus	Power	Off
Transponder Config.	Comm.	RF Switches configured for HGA	Isolation Valve	Prop.	Open
Reaction Wheels	GNC	On	Prop. Heaters	Prop.	Enabled
Star Trackers	GNC	On	CATBED Heaters	Prop.	Off
IMU/Gyro	GNC	On	Prop. Thrusters (TBR)	Prop.	On
ACS S/W Mode	GNC	Point Mode	Thermal Pumps?	Thermal	On
Survival Heater Bus	Thermal	Enabled	S/C Ops Heaters	Thermal	On
Inst. Survival HTRs	Thermal	Enabled	Inst. Ops Heaters	Thermal	Off
Deployment HTRs	Thermal	Enabled			

3.1 Spacecraft Commissioning

Ground Segment Concepts

- Ground Network
  - Supporting various data rates and modes
  - Generate tracking data
- MOC
  - Perform commissioning sequence
  - Spacecraft engineers at MOC supporting activities
  - MOC operates on extended operations (12 to 16 hrs per day)
  - MOC forwards real-time and stored engineering data to the instrument SOCs
- Flight Dynamics
  - Process tracking data
  - Generate mission products on a weekly basis

3.2 Integrated Instrument Commissioning

Integrated Instrument Commissioning

- Instrument Activation Activities:
  - Deploying any doors or protective covers
  - Powering electronic components
  - Running functional checks on systems
  - Configuring instruments for Cal/Val activities
  - Spacecraft will collect and stored instrument data on SSR
- Instruments Cal/Val Activities:
  - Perform initial Cal/Val activities as defined by the science team to validate the instruments performance
  - Based on Cal/Val activities, instrument operating parameters are adjusted to improve performance
- Final Mission Orbit Insertion:
  - Additional two burns are needed to reach the final mission orbit of 50 km
  - Burns sequence are similar to the LOI burns:
    - » Configuring prop. System (enable CatBed, thrusters, etc)
    - » Pointing S/C
    - » Transition to delta-V mode
    - » Return to 3-Axis point and nominal pointing

3.2 Integrated Instrument Commissioning

Ground Segment Concept:

- Ground Network:
  - Follows a typical scenario support
  - At least 30 minutes of S-Band support per orbit, more can be added depending on final Cal/Val plan
  - Dump SSR at the one Ka site
- MOC
  - Executes the Cal/Val activities through ground procedures or on-board stored commanding
  - Real-time housekeeping data is forwarded to the instrument SOCs
  - MOC is staffed by spacecraft and instruments engineering teams
  - Mission products are distributed to all ground elements
- Flight Dynamics
  - Process tracking data
  - Generate mission products
  - Monitor commissioning orbit and plan for transition to final mission orbit
- Instrument SOCs
  - Backup engineering support for instruments
  - Can receive real-time housekeeping telemetry from the MOC
  - Receive stored measurement data from the MOC for processing
  - Forwards results of data analysis to engineering team at the MOC for additional Cal/Val activity planning

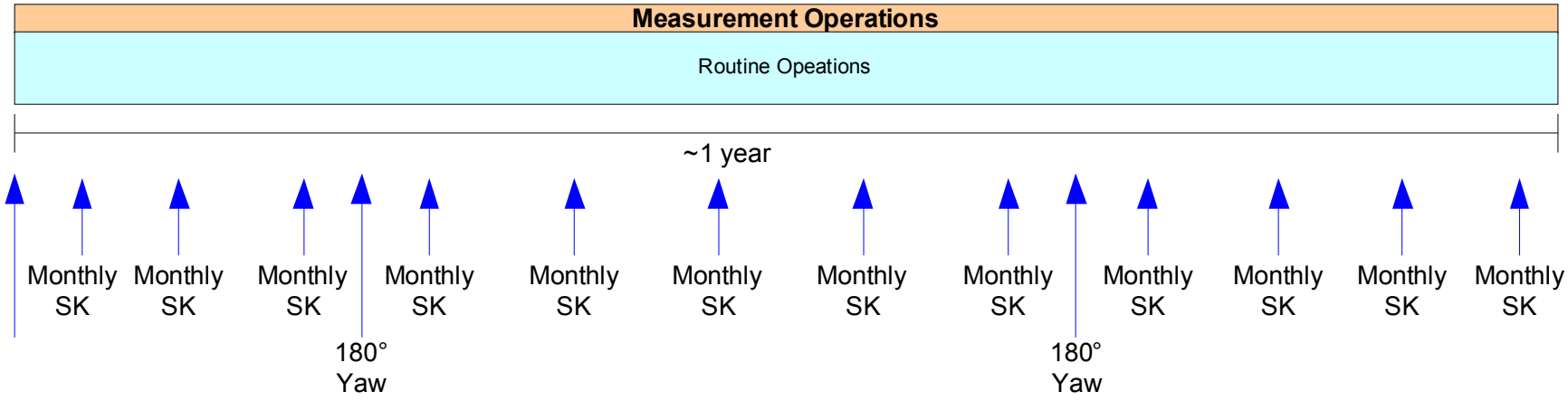
3.2 Integrated Instrument Commissioning

LRO Orbiter (Space Segment) Integrated Instrument Commissioning Configuration (TBR)					
Component/System	**Category**	**Configuration**	**Component/System**	**Category**	**Configuration**
C&DH Box	C&DH	On	LROC	Inst.	On
Solid State Recorder	C&DH	On	LOLA	Inst.	On
C&DH S/W Mode	C&DH	Normal Mode (TBR)	LEND	Inst.	On
C&DH S/W Config	C&DH	Nominal Config.	CRaTER	Inst.	On
R-T Telemetry	C&DH	16 kbps (Nominal)	LAMP	Inst.	On
Cmd Rate	C&DH	4 kbps (Nominal)	Diviner	Inst.	On
Comm. Cards	C&DH	On	Battery	Power	Online (Cycle)
S-Band Receivers	Comm.	On	PSE	Power	On
S Band Xmitter	Comm.	On	Servo Drive Bus	Power	On
Ka Band Xmitter	Comm.	Cycle	Deployment Bus	Power	Off
Transponder Config.	Comm.	RF Switches configured for HGA	Isolation Valve	Prop.	Open
Reaction Wheels	GNC	On	Prop. Heaters	Prop.	Enabled
Star Trackers	GNC	On	CATBED Heaters	Prop.	Off
IMU/Gyro	GNC	On	Prop. Thrusters (TBR)	Prop.	On
ACS S/W Mode	GNC	Point Mode	Thermal Pumps?	Thermal	On
Survival Heater Bus	Thermal	Enabled	S/C Ops Heaters	Thermal	On
Inst. Survival HTRs	Thermal	Enabled	Inst. Ops Heaters	Thermal	On
Deployment HTRs	Thermal	Enabled			

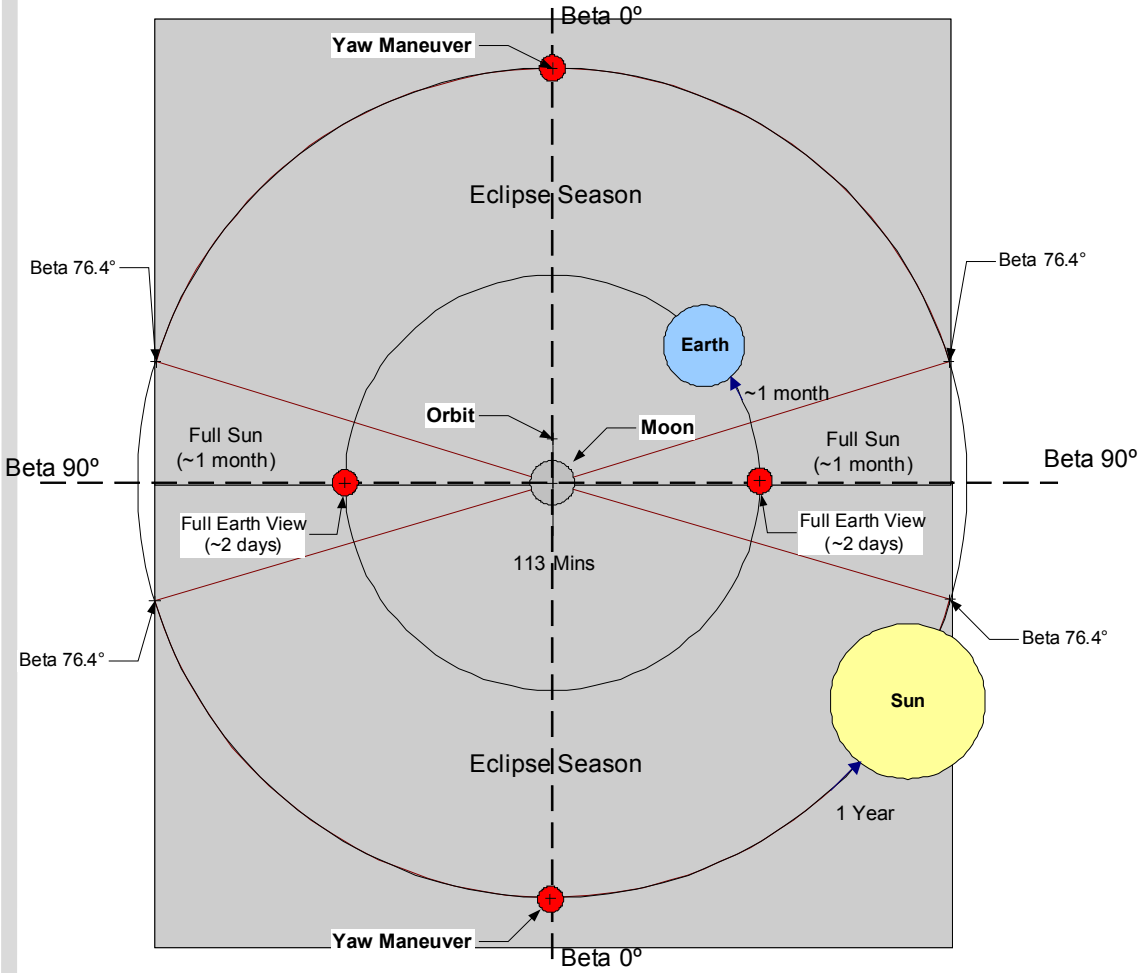
4.0 Measurement Operations

Measurement operations is the routine mission phase for LRO. The phase starts once LRO enters it's final mission orbit and all spacecraft and instruments commissioning activities are complete. Throughout the measurement operations, there are five sub-phases:

- Routine Operations
- Station Keeping/Calibrations
- Lunar Occultation
- Yaw Maneuvers
- Safehold



4.1 Routine Operations



Orbit View

Twice a year, LRO will be in full Sun for roughly 1 month (Continuous)

Max Lunar Occultation is 48 minutes per orbit

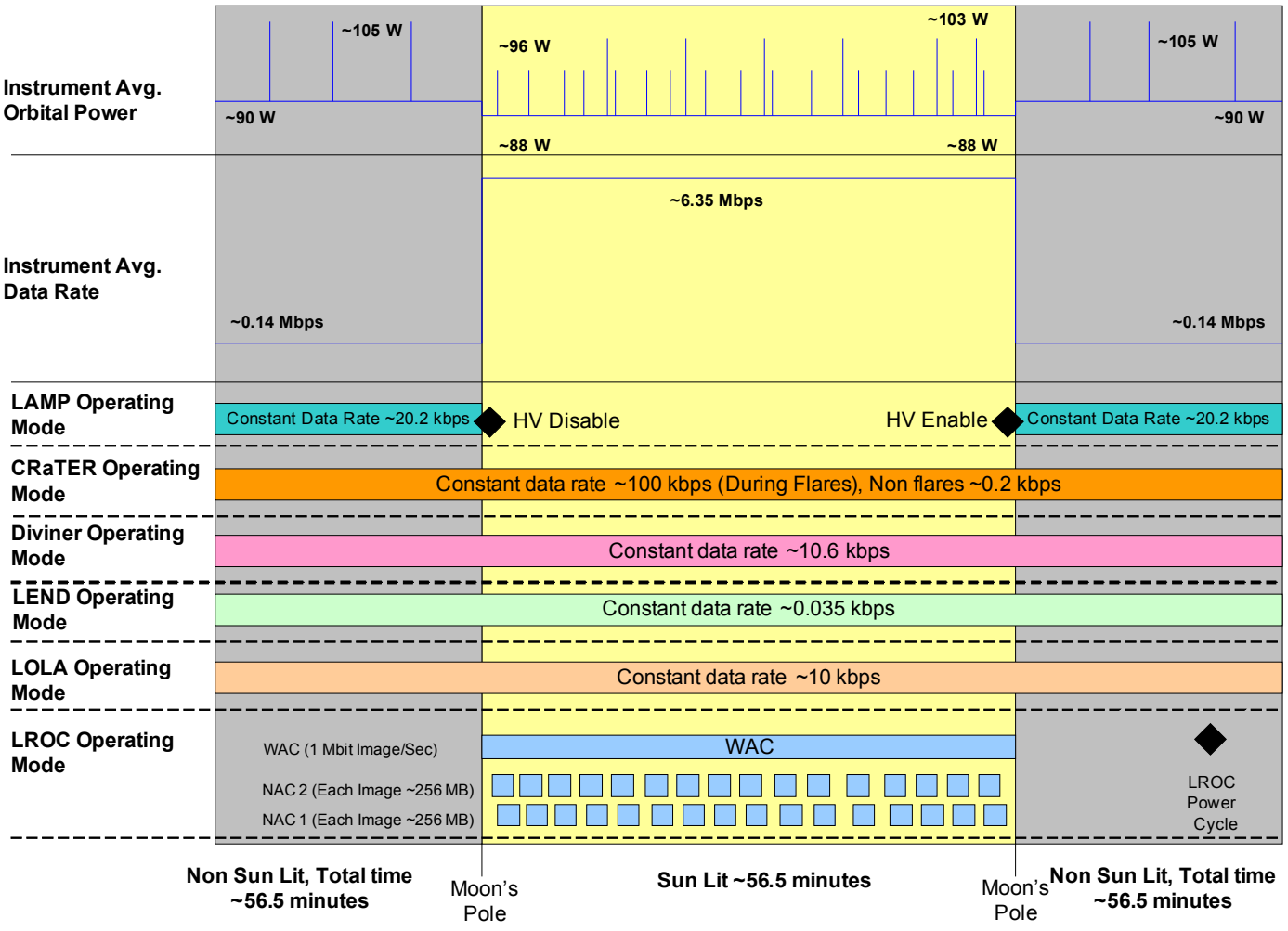
Twice a year, LRO will perform a yaw maneuver to keep the Sun on the correct side of the spacecraft

Twice a month, LRO's orbit will be in full view of the Earth for a period of approximately 2 days

Once a month, LRO will perform a set of station-keeping maneuvers (combined Delta-V & Delta-H). Maneuvers will interrupt science for 1 orbit each month (~2 hrs)

Twice a year (on average) the Earth will pass between the Moon and Sun (Lunar Eclipse), interrupting science for approximately 3 orbits – Worse case (~6 hrs)

4.1 Routine Operations (Daily Measurement Timeline)



4.1 Routine Operations

Space Segment Concepts:

- Mission Orbit:
  - 50 km (+/- 20 km)
  - Approximately 90° lunar equatorial inclination – drifts about 0.5 °/year
  - Orbit period: 113 minutes
- Orbiter Pointing:
  - Nadir pointing to control accuracy of 60 arc-sec (3σ) per axis
  - Pointing stability (3σ per axis):
    - » 5 arc-sec/axis over 1 ms
    - » 10 arc-sec/axis over 100 ms
    - » 20 arc-sec/axis over 4 sec
- Nominal command rates ~2 kbps or 4 kbps
- Nominal real-time telemetry rates ~16 kbps or 32 kbps
- Spacecraft housekeeping storage rate to the SSR is 32 kbps

4.1 Routine Operations

Space Segment Concepts (Cont.)

- LROC
  - Takes between 9 and 18 NAC image pairs each orbit (primary image collection over the Sun-lit portion of the orbit)
  - WAC collects image ~1 Mbps over Sun-lit portion of the orbit
  - Each NAC image takes 15 seconds to fill the camera buffer
  - Camera buffer is transferred to the spacecraft SSR in approximately 206 seconds
  - LROC observations include occasional slews
    - » Slews up to 20 degrees are planned
    - » Spacecraft slews are 20 seconds (allow NAC buffer to fill for image). Slew time does not take into account maneuver and settling time.
    - » LROC requested 3% of the observations include slews and that the slews are evenly distributed over the year
  - Requires daily command sequence to control the WAC and NAC images
    - » Command sequence is generated by the LROC SOC and transferred to the GSFC MOC for processing
  - LROC images are compressed by LROC ~1:1.7 compression ratio
  - LROC is powered cycle during the night portion of the orbit, power cycle is performed out of the stored command load
- LOLA
  - Instrument is on and collects measurement data over the entire orbit at ~10 kbps rate
  - Does not require daily command sequences, occasional real-time commands may be required to adjust instrument parameters
- LEND
  - Instrument is on and collects measurement data over the entire orbit at ~0.035 kbps rate

4.1 Routine Operations

Space Segment Concept (Cont.)

- LAMP
  - Instrument is collecting measurement data over the night portion of the orbit at a rate of 20.2 kbps
    - » LAMP's HV is disable prior to crossing the terminator line and enabled shortly after crossing the terminator line
    - » Baseline concept calls for this sequence to be in the daily load based on flight dynamics predicts. Due to the uncertainty in the predicts (~5 seconds), alternative solutions may be looked at.
  - LAMP Housekeeping rate is ~800 bps
- CRaTER
  - Instrument is collecting measurement data over the entire orbit
  - Two possible data rates: 0.2 kbps during non-flare conditions, 100 kbps during flare conditions
    - » Flare conditions could last for a few days
- Diviner
  - Instrument is collecting measurement data over the entire orbit at a rate of 10.6 kbps
  - Instrument performs internal calibration throughout the orbit, ~12 times per orbit
  - Diviner needs a signal/command from the spacecraft when crossing the Moon's equator (within 2 to 3 seconds).

4.1 Routine Operations

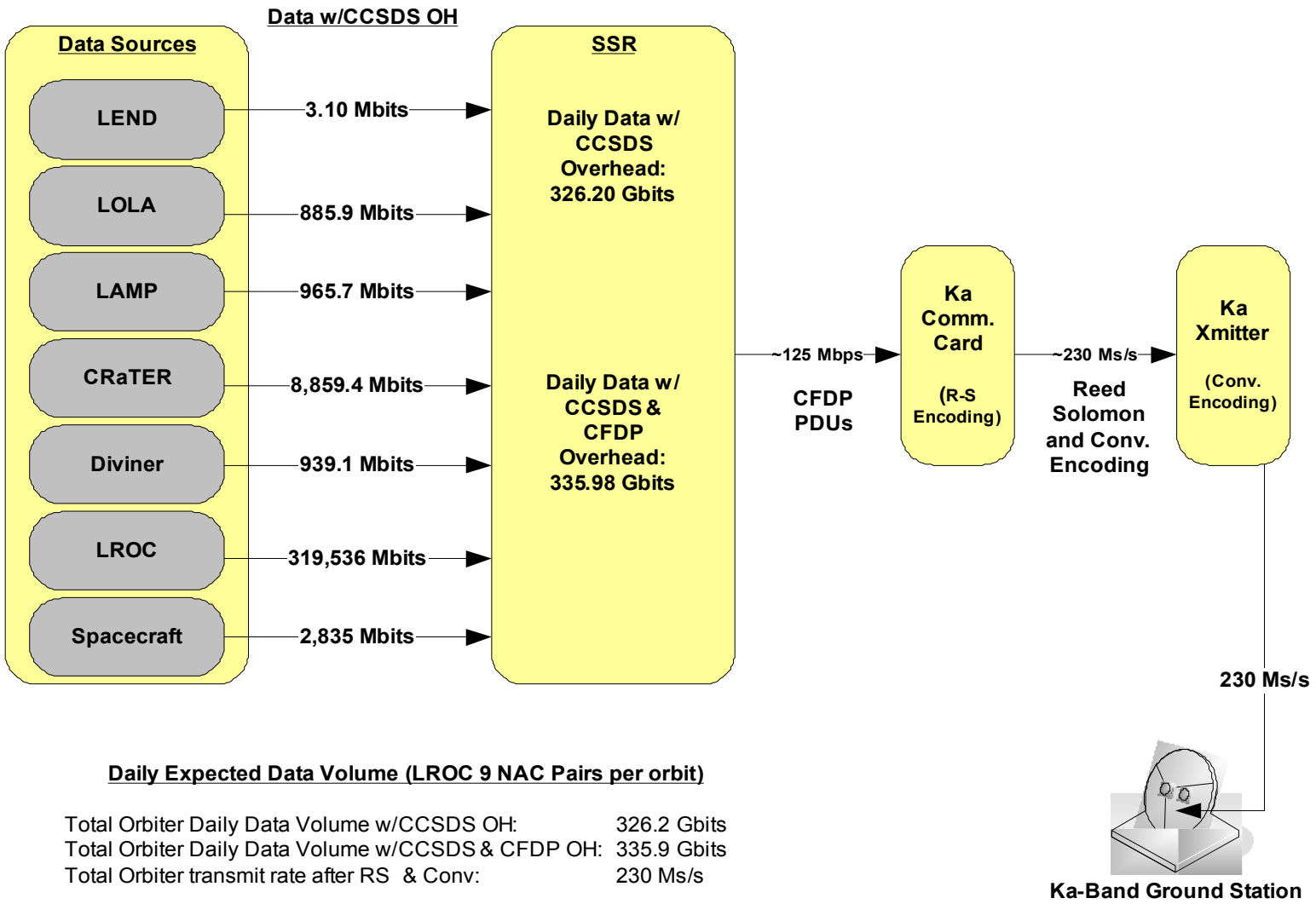
Daily Data Calculation assuming 16 NAC pairs and CRaTER sampling at 100 kbps

LRO Data Calculation Summary

Data Source	Raw Rate (kbps)	Data Rate w/OH (kbps)	Op Time per Orbit (min)	Raw Data per Orbit (Mbits)	Orbit Data w/CCSDS OH (Mbits)	Daily Data w/CCSDS OH (Mbits)	Daily Data w/CFDP OH (Mbits)	Daily Data w/R-S OH (Mbits)	Min Per File	File Size (Mbits)	File Size (kBytes)	Files per Orbit	Files per Day
LOLA	10	10.50	113.0	66.21	69.52	885.94	912.52	1,049.39	5	3.08	393.75	22.6	288.0
LEND	0.035	0.04	113.0	0.23	0.24	3.10	3.19	3.67	113	0.24	31.15	1.0	12.7
LAMP Sci	20.2	21.21	56.5	66.87	70.22	894.80	921.64	1,059.89	5	6.21	795.38	22.6	288.0
LAMP HK	0.8	0.84	113.0	5.30	5.56	70.88	73.00	83.95	113	5.56	711.90	1.0	12.7
CRaTER	100	105.00	113.0	662.11	695.21	8,859.38	9,125.16	10,493.93	113	695.21	88,987.50	1.0	12.7
Diviner	10.6	11.13	113.0	70.18	73.69	939.09	967.27	1,112.36	5	3.26	417.38	22.6	288.0
LROC WAC	1024	1000	56.5	3,390.00	3,390.00	43,200.00	44,496.00	51,170.40	5	292.97	37,500.00	22.6	288.0
LROC NAC	N/A	N/A	56.5	38,550.59	38,550.59	491,264.13	506,002.06	581,902.37	N/A	1,204.71	154,202.35	32.0	407.8
Spacecraft HK	32	32	113	211.88	222.47	2,835.00	2,920.05	3,358.06	5	9.38	1,200.00	22.6	288.0

SSR Daily Storage w/CCSDS OH:	536.09 Gbits
SSR Daily Storage w/CCSDS & CFDP OH:	552.17 Gbits
SSR Orbit Storage w/CCSDS OH:	42.07 Gbits
SSR Orbit Storage w/CCSDS & CFDP OH:	43.33 Gbits
Total Data to be dumped daily w/all OH & Coding:	1,269.99 Gsymbols

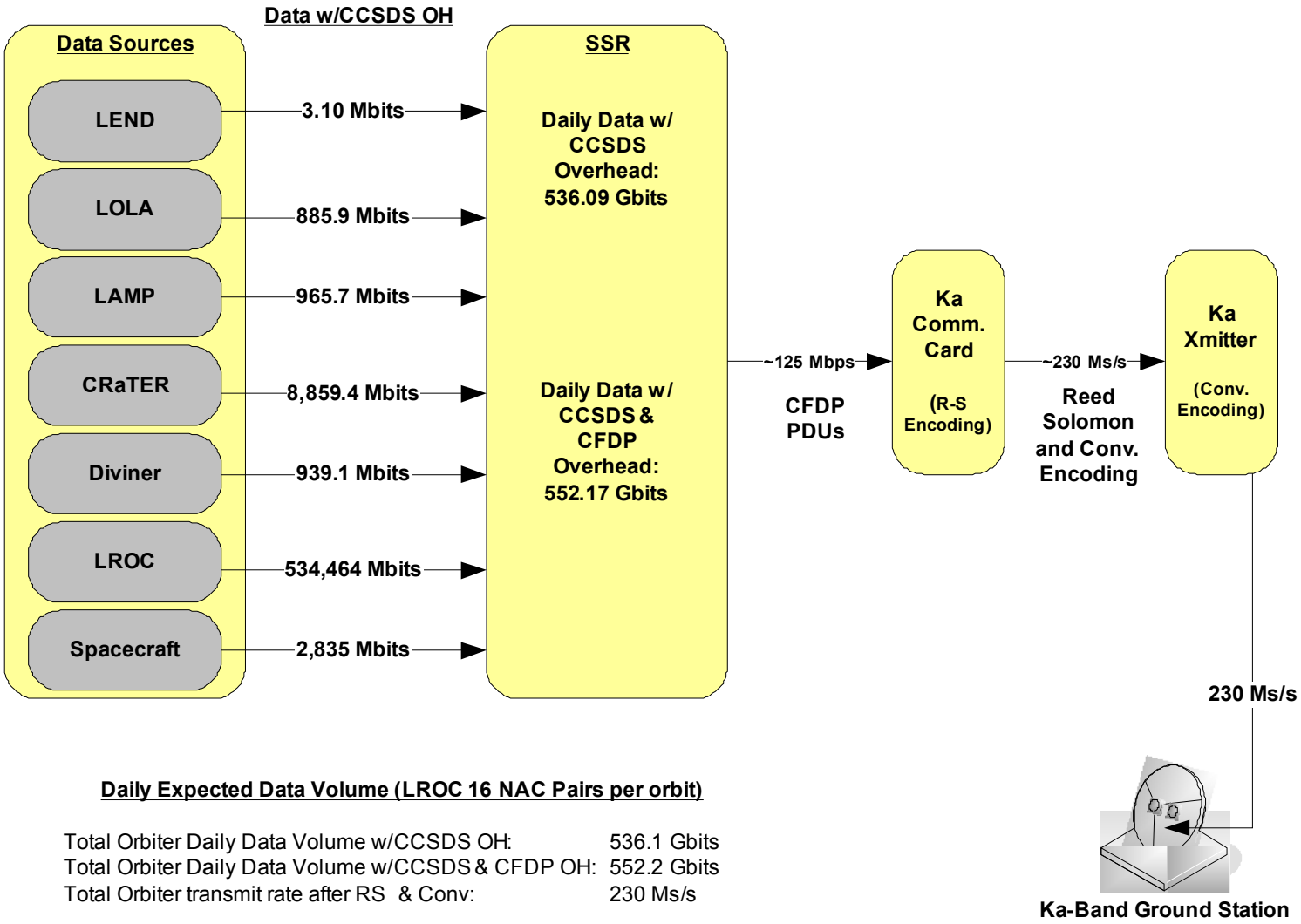
4.1 Routine Operations (Min. Data Volume Case)



Daily Expected Data Volume (LROC 9 NAC Pairs per orbit)

Total Orbiter Daily Data Volume w/CCSDS OH:	326.2 Gbits
Total Orbiter Daily Data Volume w/CCSDS & CFDP OH:	335.9 Gbits
Total Orbiter transmit rate after RS & Conv:	230 Ms/s

4.1 Routine Operations (Max Data Volume Case)

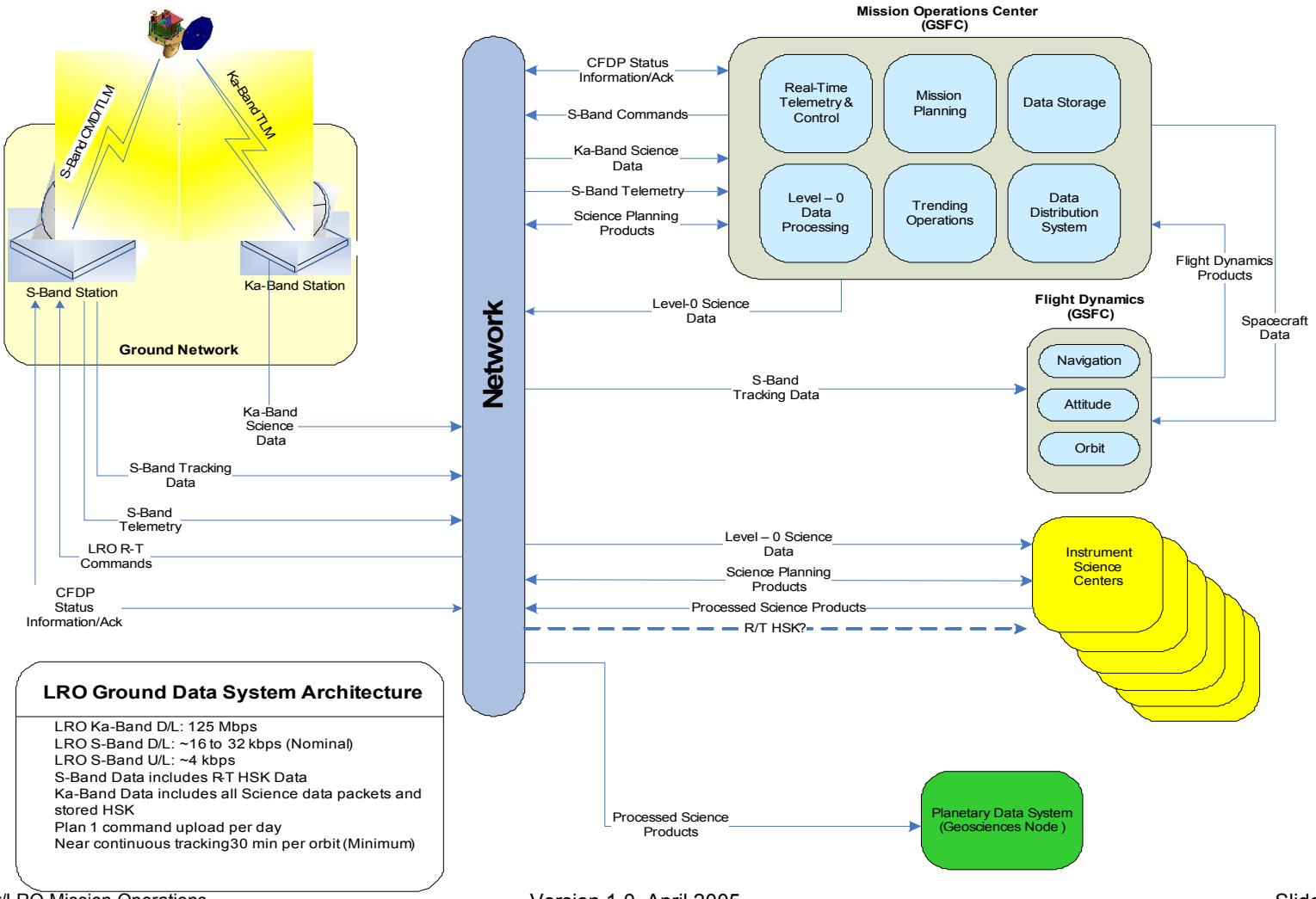


Daily Expected Data Volume (LROC 16 NAC Pairs per orbit)

Total Orbiter Daily Data Volume w/CCSDS OH:	536.1 Gbits
Total Orbiter Daily Data Volume w/CCSDS & CFDP OH:	552.2 Gbits
Total Orbiter transmit rate after RS & Conv:	230 Ms/s

4.1 Routine Operations

LRO Ground System Architecture



LRO Ground Data System Architecture

- LRO Ka-Band D/L: 125 Mbps
- LRO S-Band D/L: ~16 to 32 kbps (Nominal)
- LRO S-Band U/L: ~4 kbps
- S-Band Data includes R-T HSK Data
- Ka-Band Data includes all Science data packets and stored HSK
- Plan 1 command upload per day
- Near continuous tracking30 min per orbit (Minimum)

4.1 Routine Operations

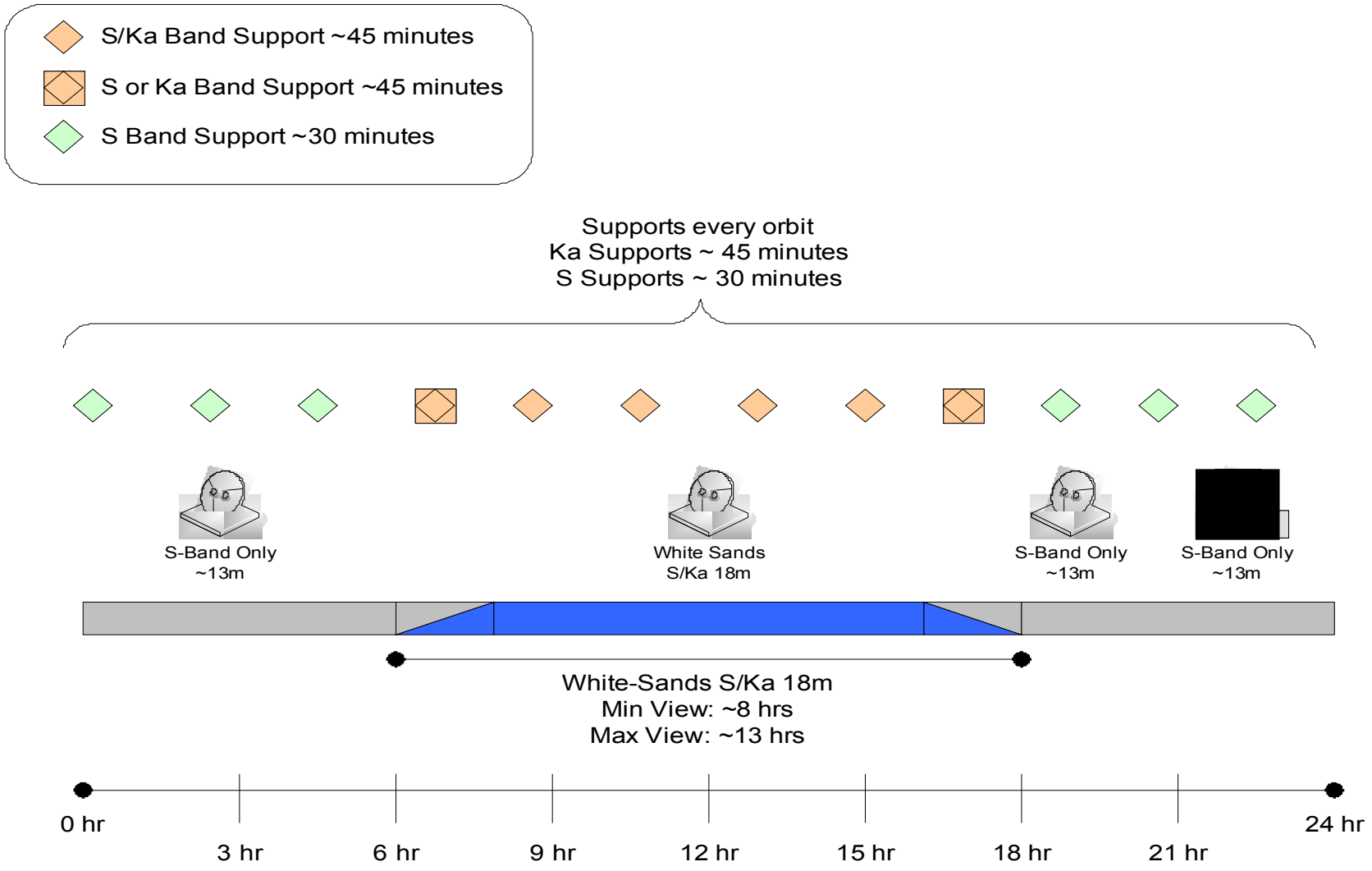
Ground Segment Concepts (Cont):

- Ground Network Concept:
  - One new 18m aperture Ka/S dual feed ground antenna located at White Sands.
  - Combination of 2 to 3 existing NENS/GN/Commercial S-band stations to provide remaining S-Band daily coverage.
    - » Additional sites S-Band sites may be utilized for backup/contingency operations.
- Ground Network Communication Characteristics:
  - Ka-Band Downlink (25.5 – 27 GHz)
    - » Support 284 Msymbols downlink rate/1311 Gsymbols per day
    - » Support CFDP CCSDS file data protocol
    - » Support Reed-Solomon convolution encoding schemes
    - » Required Station G/T(2) = 45 dB/K
  - S-Band Up/Downlink TT&C (2104/2287 MHz)
    - » 1 mm/s Doppler (2-way)
    - » 15 m ranging (2-way)
    - » Support command rates of 2, 4,16, & 32 kbps (1)
    - » Support telemetry rates of 4,16,32, & 300 kbps (1)
    - » Near Continuous S-band coverage required
      - → Minimum: 30 minutes per orbit during lunar near-side passage
      - → Highly desirable: 60 minutes per orbit during lunar near-side passage
    - » Required Station EIRP(2) = 94 dBm into HGA & 109 dBm into Omni antennas
    - » Required Station G/T(2) = 20 dB/K

Note (1) : S-band required rates dependent on final selection of LRO S-band space segment transponder and C&DH requirements. To be determined prior to PDR.

(2) Final G/T and EIRP requirements dependent on site location

4.1 Routine Operations – Ground Network Support)



4.1 Routine Operations – Ground Network Ka Dump Concept

LRO 1-Ka Ground Station (White Sand) Dump Scenario								
	Daily		Orbit					
Data Volume w/CCSDS OH (Min):	326.20	Gbits	25.60	Gbits				
Data Volume w/CCSDS OH (Max):	536.09	Gbits	42.07	Gbits				
Data Volume w/CCSDS & CFDP OH (Min):	335.98	Gbits	26.37	Gbits				
Data Volume w/CCSDS & CFDP OH (Max):	552.17	Gbits	43.33	Gbits				
	Contact #1		Contact #2		Contact #3		Contact #4	
Pass Length:	45	minutes	45	minutes	45	minutes	45	minutes
Time Since Last Pass:	1044	minutes	113	minutes	113	minutes	113	minutes
Orbits Since Last Pass:	9.24	orbits	1	orbits	1	orbits	1	orbits
Data Recorded (Min):	236.49	Gbits	25.60	Gbits	25.60	Gbits	25.60	Gbits
Data Recorded (Max):	388.66	Gbits	42.07	Gbits	42.07	Gbits	42.07	Gbits
Data to be Dumped (Min):	236.49	Gbits	25.60	Gbits	25.60	Gbits	25.60	Gbits
Data to be Dumped (Max):	388.66	Gbits	173.76	Gbits	42.07	Gbits	42.07	Gbits
Symbols (Min):	558.12	Gsym	60.41	Gsym	60.41	Gsym	60.41	Gsym
Symbols (Max):	917.24	Gsym	410.08	Gsym	99.28	Gsym	99.28	Gsym
D/L Capacity:	606.45	Gsym	606.45	Gsym	606.45	Gsym	606.45	Gsym
Remaining Data (Min):	0.00	Gbits	0.00	Gbits	0.00	Gbits	0.00	Gbits
Remaining Data (Max):	131.69	Gbits	0.00	Gbits	0.00	Gbits	0.00	Gbits
Minutes Remaining (Min):	3.59	minutes	40.52	minutes	40.52	minutes	40.52	minutes
Minutes Remaining (Max):	-23.06	minutes	14.57	minutes	37.63	minutes	37.63	minutes

4.1 Routine Operations

Ground Segment Concept (Cont.)

- Ground Network Contingency Operations:
  - With only 1 Ka-band site for high measurement downlink, interruptions to measurement observations are increased due to equipment failure and routine maintenance
    - » Newer antenna will hopefully offset equipment failure risk
    - » Routine maintenance can be schedule during off hours
  - If failure to antenna does occur, a couple of scenarios are possible to maintain current or modified observations:
    - » Using the 300kbps S-Band rate, can dump all but LROC data for 1 day
      - ➔ Need additional coverage to replace White Sands, possible sites are Hawaii, and Wallops?
    - » Fall back to DSN for S-Band coverage. Using DSN we can utilize the 2.5 Mbps S-Band rate. Dump all non LROC data plus modified LROC image sequence.

4.1 Routine Operations

Ground Segment Concepts (Cont.)

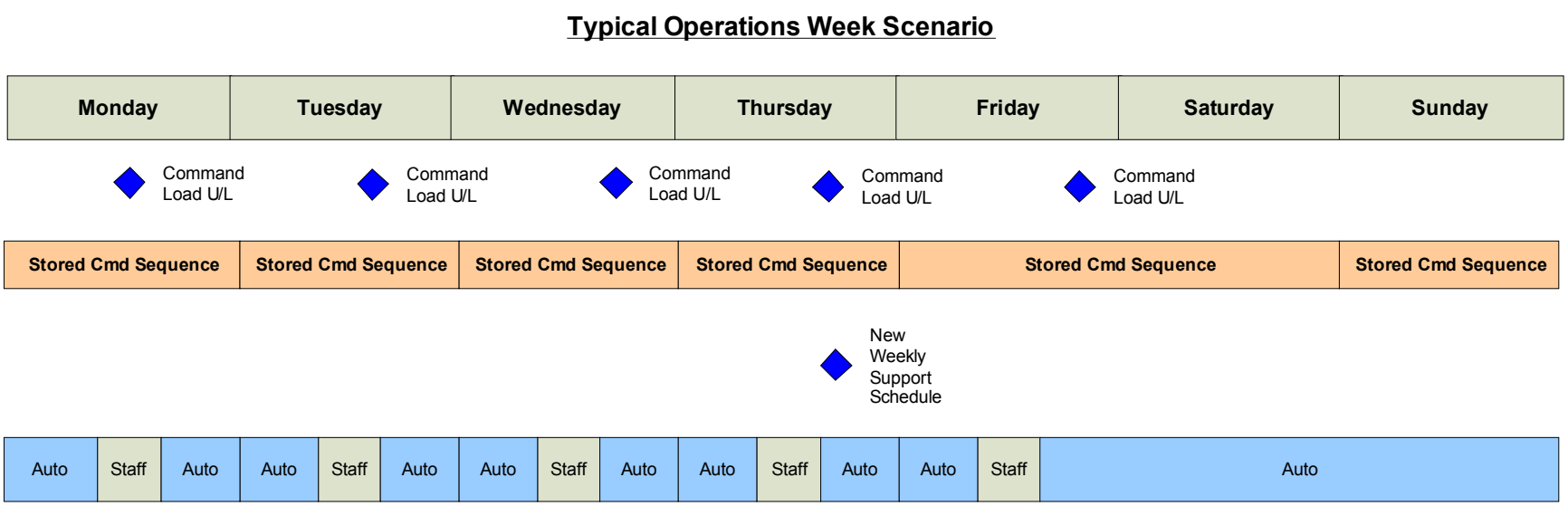
- Flight Dynamics
  - Flight Dynamics Facility (FDF):
    - » Perform orbit determination and attitude support to LRO
    - » Generates flight dynamics mission products for operations
    - » Receives and process tracking data
    - » Generates new acquisition data for ground network
  - Flight Dynamics Analysis Branch
    - » Responsible for maneuver and navigation support
    - » Develops all maneuver plans. Plans are sent to the MOC for execution.
      - → Develops trajectory path to the Moon
      - → Plans LOI burns
      - → Develops monthly station-keeping maneuvers

4.1 Routine Operations

Ground Segment Concepts (Cont.):

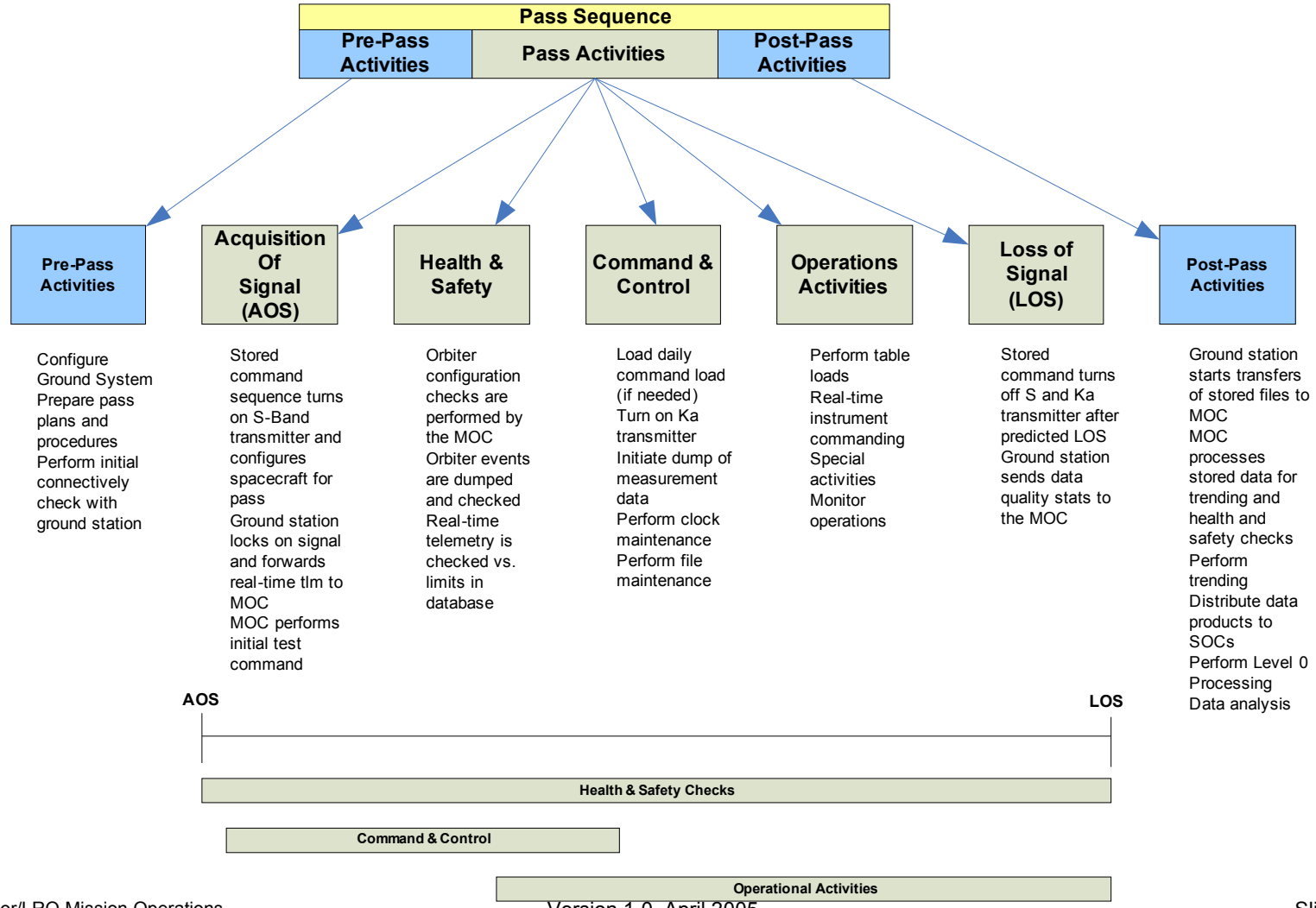
- Mission Operations Center
  - Performs daily operational activities
    - » Generating daily command load
    - » Monitor orbiter health and safety
    - » Performs short and long term trending
    - » Stores spacecraft data for the life of the mission
    - » Temporary stores measurement data until verification of receipt from instrument SOCs
    - » Distributes all mission products including pass schedules, Flight dynamics products, operation events, logs, etc
    - » Performs data accountability on all mission data
    - » Logs and tracks all ground and orbiter anomalies
    - » Coordinates operations with instrument and science teams
  - Operations team will staff MOC Monday's through Friday's (8x5 shift)
    - » Automation will be used to monitor orbiter during off-hours through the week and weekend
    - » Daily load uplinked on Friday will cover weekend operations through Monday
    - » Automation system will alert operations team of either ground system or orbiter problems
  - Daily Command Load will include:
    - » Commands to configure the spacecraft for all ground passes
    - » Initiate data dumps from SSR and any orbiter events
    - » Contain any instrument control commands that are required

4.1 Routine Operations



4.1 Routine Operations

LRO Typical Pass Scenario



4.1 Routine Operations

Ground Segment Concepts (Cont.)

- Instrument SOCs
  - Prepare and deliver daily instrument command sequences to the MOC (if needed)
    - » Command sequences are processed and typically incorporated into the daily command load
    - » Final command load product is transferred back to the instrument SOCs
  - During real-time contacts, the real-time orbiter or instrument housekeeping data can be forwarded to the SOCs. At this time, only CRaTER and LAMP have requested this. All data, both measurement and housekeeping data will be transferred post-pass in files.
  - Receive measurement data files from the MOC and process Level 1 and higher products. Instrument SOCs transfer the data products to the PDS.
  - Monitor instrument health and perform trending
  - Responsible for any instrument FSW updates and table updates, sends verified file to the MOC for uplink
  - Receive mission data products from the MOC based on the ground system ICD

4.2 Station-Keeping/Calibrations Sub-Phase

Station-Keeping Operations:

- Once in the final mission orbit, monthly station-keeping maneuvers are required to maintain the orbit
- Maneuvers will take less than 1 orbit to perform and involves two small burns (with yaw maneuvers)
- SK schedule will be provided to the instrument SOCs at least 1 week before maneuver
- FDAB generates the maneuver plan and forwards it to the MOC for execution
- Each SK maneuver will have the following sequence:
  - Configure the orbiter for maneuver operations. Configure instruments, propulsion, GNC, etc
  - Slew orbiter to desired attitude
  - Perform maneuver burn
  - Slew back to nominal pointing attitude
- If possible, SK maneuvers will be performed during ground station coverage. May require DSN since HGA can't be used
- During Delta-V maneuvers, Delta-H dumps will be coordinated with each burn
- The ground will track fuel usage for each burn
- Flight Dynamics will monitor and release burn performance report
- Nominal instrument observations will be interrupted during SK operations, max interruption should be less than 1 orbit

4.2 Station-Keeping/Calibrations Sub-Phase

Calibration Operations

- To minimize observation interruptions, monthly instrument calibrations can be coordinated during the same day as monthly SK operations.
- Calibrations can occur before the SK maneuver
- Using the same day as SK operations, allows the science team to plan and coordinate desired integrated calibrations.
- Operations team, flight dynamics, and science team will coordinate and develop the integrated calibration sequence

4.3 Lunar Eclipse Sub-Phase

Lunar Eclipse Concept:

- Twice a year (on average), the Earth will pass between the Moon and Sun causing partial/full lunar eclipse
  - Worst duration is ~150 minutes
    - » 2011 worst case is 160 minutes
  - Measurement operations will be interrupted during eclipse if duration is longer than the nominal lunar occultation time ~50 minutes
- Orbiter will be placed in a low power mode
  - Instruments will be powered off
    - » Depending on the length of eclipse, instruments could be powered off for at least 6 orbits
      - ➔ 6 orbits covers the eclipse time, configuration time before the eclipse, and re-configuring the orbiter following the eclipse
  - Spacecraft components (if not needed) will be powered off
  - No Ka-Supports will be scheduled
  - Reduced or modified S-Band supports may be needed
  - Orbiter will be maintained to within +/- 45° (TBR) of inertial sun at eclipse exit
  - Orbiter battery may have 80% DoD, nominal DoD is ~30%

4.3 Lunar Eclipse Sub-Phase

LRO Orbiter (Space Segment) Lunar Eclipse Configuration (TBR)					
Component/System	**Category**	**Configuration**	**Component/System**	**Category**	**Configuration**
C&DH Box	C&DH	On	LROC	Inst.	Off
Solid State Recorder	C&DH	Off (TBR)	LOLA	Inst.	Off
C&DH S/W Mode	C&DH	Normal Mode (TBR)	LEND	Inst.	Off
C&DH S/W Config	C&DH	Nominal Config.	CRaTER	Inst.	Off
R-T Telemetry	C&DH	16 kbps (Nominal)	LAMP	Inst.	Off
Cmd Rate	C&DH	4 kbps (Nominal)	Diviner	Inst.	Off
Comm. Cards	C&DH	On	Battery	Power	Online (Discharging)
S-Band Receivers	Comm.	On	PSE	Power	On
S Band Xmitter	Comm.	Cycle	Servo Drive Bus	Power	On
Ka Band Xmitter	Comm.	Off	Deployment Bus	Power	Off
Transponder Config.	Comm.	RF Switches configured for HGA	Isolation Valve	Prop.	Open
Reaction Wheels	GNC	On	Prop. Heaters	Prop.	Enabled
Star Trackers	GNC	Off (TBR)	CATBED Heaters	Prop.	Off
IMU/Gyro	GNC	On	Prop. Thrusters (TBR)	Prop.	Off
ACS S/W Mode	GNC	Safe-Mode?	Thermal Pumps?	Thermal	On
Survival Heater Bus	Thermal	Enabled	S/C Ops Heaters	Thermal	Off
Inst. Survival HTRs	Thermal	Enabled	Inst. Ops Heaters	Thermal	Off
Deployment HTRs	Thermal	Disabled			

4.4 Yaw Maneuver Sub-Phase

Twice a year, a 180° yaw maneuver is required to keep the Sun on the correct side of the orbiter

- Yaw maneuver is required as the mission reaches the beta 0° condition
  - Power and Thermal will determine when the yaw maneuver is performed ~+/- 5° (TBR)
  - Orbiter will not sweep anti-Sun side through the Sun
  - Maneuver should take less than 1 orbit
    - » Interruption in nominal measurement collection
  - Maneuver will be done using the reaction wheels and with ground coverage
    - » Requires DSN support since HGA can't be used during maneuver

4.5 Safehold Sub-Phase

Orbiter will have a tier safing implementation

Safing monitors will be implemented through both hardware and software

- Safing monitors and actions will be documented in the LRO System Safing Implementation Document
- Monitors can include instrument points

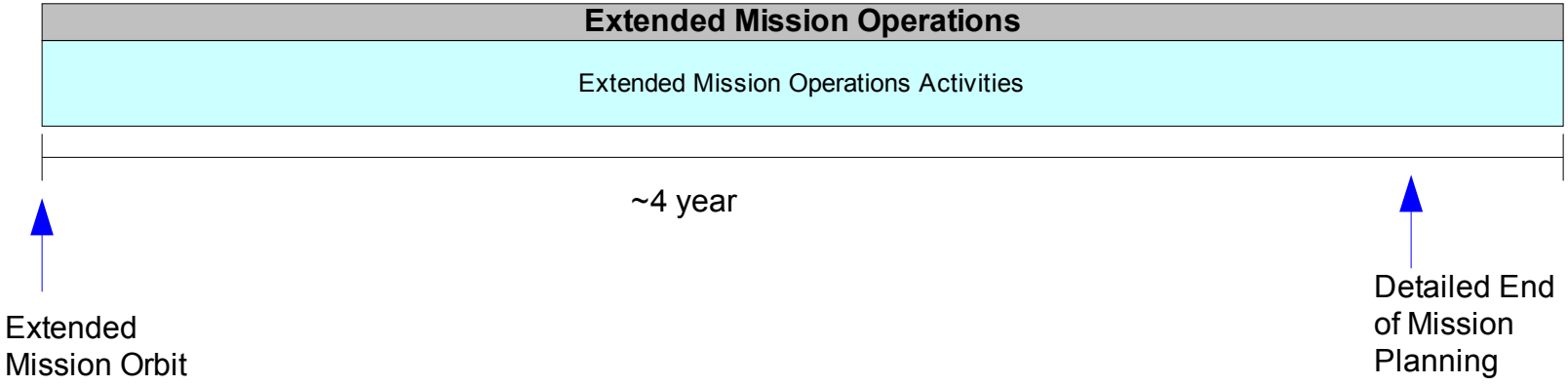
In Safehold, the instruments will be powered off and the orbiter will be in low power mode

- Orbiter is in attitude and power safe condition until ground diagnose the problem
- Once ground determines the problem, orbiter will be re-configured through ground commands to nominal operating level.

Safing implementation details are still in work

5.0 Extended Mission Operations Phase

After approximately 1 year of nominal measurement operations, LRO will enter the extended mission operation phase. Depending on mission requirements, goals for extended mission operations may vary. Depending on fuel resources, extended mission operation phase could last up to an additional 4 years.



5.0 Extended Mission Operations Phase

Depended on goals for phase, mission orbit may be adjusted to a lower fuel maintenance orbit (90x110 km)

Possible goals for extended mission operations phase

- Comm. relay support for future RLEP missions
- Comm. S/W radio
- Extended measurement operations
  - Continue measurement operations with available resources either in 50 km mission orbit or lower fuel maintenance orbit

6.0 End-of-Mission Disposal

Planetary Protection Category II

- NPR 8020.12
  - Minimize the likelihood of accidental impact
  - Provide End-of-Mission report providing impact location
- Approach
  - Continue to fly mission until fuel is exhausted

Acronyms List

Acronym	Definition	Acronym	Definition	Acronym	Definition
Acq	Acquisition	ITOS	Integration Test & Operations System	TBD	To Be Determined
ACS	Attitude Control System	KF	Kalman Filter	TBR	To Be Resolves
AOS	Acquisition of Signal	km	Kilometer	U/L	Uplink
ATS	Absolute Time Sequence	KSC	Kennedy Space Center		
C&DH	Command & Data Handling	LOI	Lunar Orbit Insertion		
Cal/Val	Calibration/Validation	LOS	Loss of Signal		
CDR	Critical Design Review	LRO	Lunar Reconnaissance Orbiter		
CFDP	CCSDS File Delivery Protocol	LV	Launch Vehicle		
ConOps	Concept of Operations	MCC	Mid Course Correction		
D/L	Dow nlink	MOC	Mission Operations Center		
DoD	Depth of Discharge	MOC	Mission Operations Center		
DS	Data Storage	MRT	Mission Readiness Test		
DSN	Deep Space Netw ork	OH	Overhead		
FDAB	Flight Dynamics Analysis Branch	PDS	Planetary Data System		
FDF	Flight Dynamics Facility	RLEP	Robotic Lunar Exploration Program		
GN	Ground Netw ork	R-T	Real-Time		
GNC	Guidance, Navigation, Control	RTS	Relative Time Sequence		
GSE	Ground Support Equipment	RW	Reaction Wheel		
GSFC	Goddard Space Flight Center	S/C	Spacecraft		
Gsym	Giga-Symbols	S/W	Softw are		
H/W	Hardw are	SA	Solar Array		
HGA	High Gain Antenna	SK	Station-Keeping		
HV	High Voltage	SOC	Science Operations Center		
I&T	Integration & Test	SSR	Solid State Recorder		
Inst.	Instrument	ST	Star Tracker		