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Lunar Reconnaissance Orbiter (LRO) Project

Data Management Plan

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Goddard Space Flight Center
Greenbelt, Maryland

CM FOREWORD

This document is a Lunar Reconnaissance Orbiter Project controlled document. Changes to this document require prior approval of the LRO Project CCB Chairperson. Proposed changes shall be submitted to the LRO Project Configuration Management Office (CMO), along with supportive material justifying the proposed change.

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Lunar Reconnaissance Orbiter Project Data Management Plan

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1.0 INTRODUCTION

1.1 Purpose

oThis plan is intended to document the plans for data management by the Lunar Reconnaissance Orbiter (LRO) Mission throughout the project lifecycle phases, and transfer of data to the Planetary Data System (PDS) for archiving.

1.2 Scope

This plan covers archiving of raw and reduced data sets and related information to be acquired and or derived during the Lunar Reconnaissance Orbiter (LRO) Mission.

Specific aspects addressed in this plan are:

- Mission Summary and Instrument Suite Synopsis
- Roles and Responsibilities
- The total data flow including data collection, on-board storage, Ground Network, Mission Operations Center, Science Operations Centers, and the Planetary Data System
- Data Handling steps including Processing, Reprocessing, Calibration, and Validation
- Science (Measurements) Products Descriptions and associated estimated data volumes (w/ Reprocessing volumes included), Data Delivery Latencies, High Level Formats, and Contents
- Archiving Plans

1.3 APPLICABLE DOCUMENTS

The following documents (or latest revisions available) are applicable to the development and execution of this plan:

430-PLAN-000008, LRO Program Plan,
SSE MH2002, Space Science Enterprise Management Handbook
SP-6105, NASA Systems Engineering Handbook
GPG 7120.5, Systems Engineering
GPG 8700.6, Engineering Peer Reviews
NPD 8010.2C, Use of the Metric System of Measurement in NASA Programs
GPG 7120.4, Risk Management

GPG 7120.2, Project Management
GPG 1410.2.1, Configuration Management

The plan is also consistent with the following Planetary Data System document:

Planetary Data System Standards Reference, August 1, 2003, Version 3.6, JPL D-7669,

The plan requires the generation of the following Instrument Team documents:

- Data Product Software Interface Specification (SIS) for all Standard Products.

- Archive Volume Software Interface Specification (SIS) for all Standard Products.

Finally, the plan is meant to be consistent with the Level 1 Requirements, NASA, in which reduced data records and documentation are explicitly defined as deliverable products.

1.4 PROJECT OVERVIEW

1.4.1 RLEP Program Goals, Objectives, and Architecture

In January 2004, the President of the United States announced a new plan to advance the Nation's scientific, security, and economic interests through a robust space exploration program that integrates human and robotic exploration activities. This decision was documented by the *President's Space Exploration Policy Directive (NPSD31)(Goal and Objectives)*, and *A Renewed Spirit of Discovery – The President's Vision for U.S. Space Exploration (January 2004).* The specific actions required to carry out this new exploration program have been further elaborated on in the NASA response document "*The Vision for Space Exploration,*" dated February 2004. All of these documents may be found in the LRO Library at the Web site http://centauri.larc.nasa.gov/lro/lrolib.html

A joint Enterprise working group at NASA Headquarters subsequently established the following Preliminary Level Zero Lunar Program Requirements:

1. Undertake lunar exploration activities to enable sustained human and robotic exploration of Mars and more distant destinations in the Solar System.
2. Starting no later than 2008, initiate a series of robotic missions to the Moon to prepare and support future human exploration activities:
    a. Mission objectives shall include landing site identification and certification on the basis of potential resources;

   b. Measurements shall be made to support applied science and research relevant to the Moon as a step to Mars, engineering safety, and engineering boundary conditions; and
   c. Technology demonstrations and system testing shall be performed to support development activities for future human lunar and Mars mission.
3. Conduct the first extended human expedition to the lunar surface as early as 2015, but no later than the year 2020.
4. Use lunar exploration activities to further science and research.

These guiding requirements for the Lunar Program have been approved by NASA Headquarters management but await final endorsement on the basis of the recommendations from the *President's Commission on the Moon, Mars, and Beyond* (Aldridge Commission), which has been specifically charged with reviewing the implementation planning necessary to effectively meet the President's vision as outlined in NPSD31.

1.4.2 LRO Investigation Measurement Objectives

NASA established an external group entitled the LRO Objectives/Requirements Definition Team (ORDT) that met in March 2004 to assist in defining specific LRO mission goals and measurement objectives needed for the initial steps in lunar robotic exploration. From the results of this external group, NASA has established the following high priority objectives for the initial robotic elements in the Lunar Exploration Program:

- Characterization of the global lunar radiation environment and its biological impacts and potential mitigation, as well as investigation of shielding capabilities and validation of other deep space radiation mitigation strategies involving materials.
- Determination of a high spatial resolution global geodetic grid for the Moon in three dimensions:
  a. Global geodetic knowledge by means of spatially resolved topography, and
  b. Detailed topographic characterization at landing site scales.
- Assessment of the resources in the Moon's polar regions (and associated landing site safety evaluation), including characterization of permanently shadowed regions and evaluation of any water ice deposits.
- High spatial resolution global resources assessment including elemental composition, mineralogy, and regolith characteristics.

The Lunar Reconnaissance Orbiter (LRO) is the first mission within NASA's Robotic Lunar Exploration Program (RLEP). The LRO mission is focused on obtaining new data that will facilitate returning humans safely to the Moon, where testing, experiments, and operational preparations for eventual human missions to Mars may be undertaken.

1.4.3 LRO Mission Instruments

The LRO instrument compliment is comprised of six instruments.

- **Cosmic Ray Telescope for the Effects of Radiation (CRaTER)** – principal investigator Professor Harlan Spence, Boston University, Boston, MA. CRaTER will investigate the effect of galactic cosmic rays on tissue-equivalent plastics as a constraint on models of biological response to background space radiation.
- **Diviner Lunar Radiometer Experiment** – principal investigator Professor David Paige, UCLA, Los Angeles, CA. Diviner will map the temperature of the entire lunar surface at 300 meter horizontal scales to identify cold-traps and potential ice deposits.
- **Lyman-Alpha Mapping Project (LAMP)** – principal investigator Dr. Alan Stern, Southwest Research Institute, Boulder, CO. LAMP will observe the entire lunar surface in the far ultraviolet. LAMP will search for surface ices and frosts in the polar regions and provide images of permanently shadowed regions illuminated only by starlight.
- **Lunar Exploration Neutron Detector (LEND)** – principal investigator Dr. Igor Mitrofanov, Institute for Space Research, and Federal Space Agency, Moscow, Russia. LEND will map the flux of neutrons from the lunar surface to search for evidence of water ice and provide measurements of the space radiation environment which can be useful for future human exploration.
- **Lunar Orbiter Laser Altimeter (LOLA) Measurement Investigation** – principal investigator Dr. David E. Smith, NASA Goddard Space Flight Center (GSFC), Greenbelt, MD. LOLA will determine the global topography of the lunar surface at high resolution, measure landing site slopes and search for polar ices in shadowed regions.
- **Lunar Reconnaissance Orbiter Camera (LROC)** – principal investigator Dr. Mark Robinson, Northwestern University, Evanston, IL. LROC will acquire targeted images of the lunar surface capable of resolving small-scale features that could be landing site hazards, as well as wide-angle images at multiple wavelengths of the lunar poles to document changing illumination conditions and potential resources.

1.4.4 Mission Overview

The LRO spacecraft bus will be built at GSFC. Integration of the science instruments to the orbiter housekeeping systems as well as orbiter environmental testing will be performed at GSFC.

LRO is scheduled for launch in October 2008. The mission will be launched from Kennedy Space Center (KSC) on a Delta II class Expendable Launch Vehicle (ELV). The Launch Vehicle will deliver LRO into a low Earth orbit (LEO). Once in LEO, LRO will be required to perform several phasing loop maneuvers to prepare the Orbiter for it's trans-lunar cruise. Under its own propulsion system, the Orbiter will maneuver towards the moon. After a trans-lunar trajectory phase of approximately 100 hours, the spacecraft will be inserted into lunar orbit using the on-board propulsion system. The Orbiter will perform several more maneuvers to circularize the orbit and ultimately place LRO into its final polar circular orbit at 50 km (+\- 20 km) altitude. The primary mission will be conducted in a circular polar mapping orbit with a nominal altitude of 50 km for one earth year. The 3-axis stabilized spacecraft will fly a nadir-pointing attitude with off-nadir maneuvers if necessary for and compatible with the entire instrument suite.

The primary mission may be followed by an extended mission during which the spacecraft will either be transferred to a low maintenance elliptical orbit, potentially 30 by 216 km with periapsis over the lunar south pole, or flown for a short duration in a low altitude circular orbit which will be terminated in a targeted impact.

The current spacecraft bus concept is summarized below:

- 100 kg/100 W payload capacity
- 3-axis stabilized pointed platform
- Articulated solar arrays and Li-Ion battery
- Ka-band high rate downlink (~50 Mbs), S-band up/down low rate
- Centralized MOC operates mission and flows level 0 data to PI's
- Command & Data Handling (C&DH): MIL-STD-1553, RS 422, & High Speed Serial Service, PowerPC Architecture, on-board data storage, CCSDS
- Mono or bi-prop propulsion (500-700 kg fuel)

~~There are s~~Several key elements of the LRO mission~~ which~~ drive the operations concept. The chief driver of these is the large volume of data that is to be generated by the spacecraft's science instruments. The large data volume can be traced to several instrument characteristics; notably, the combination of high-resolution cameras and increased cadence (LROC), which together result in significantly increased data rate over previous missions. The solution to this driving requirement is to utilize a high speed bus interface, large capacity solid state recorders, Ka RF band communications, and dedicated ground stations.

Once on station, LRO will be 3-axis stabilized, nadir pointing the instruments towards the lunar surface where they will begin collecting science data. Data from the instruments will be passed across the LRO high speed or low speed data bus to the solid state recorder. Over the course of one earth day, the science data will be transmitted to the ground via the LRO Ka-Band RF system over 2 or 3 ground passes. The aggregate science data downlink rate through the Ka-Band system will be 125Mbps (not including overhead). The Ka-band science data will be received by the LRO ground station. Once through the RF receiver at the station, the science data will be streamed to the Data Distribution System (DDS) co-located with the MOC. Science data at the DDS is then sorted, placed in files, and routed accordingly to its destination Science Operations Center (SOC). In addition, a temporary local data archive is maintained at the DDS. This is to allow SOCs to retrieve any data which they may not have received due to a line outage between the DDS and the SOCs.

Instrument operations will be routine for the majority of the mission with instruments running the same science modes continuously. Periodic interruptions to routine science operations are expected. These would include spacecraft momentum dumping,~~ and~~ station keeping maneuvers, and instrument calibration maneuvers. It is currently baselined to dump momentum and perform station keeping maneuvers at the same time. It is expected to happen once a lunar month. Every six months, the spacecraft will perform a yaw maneuver to keep the sun on the solar array side of the spacecraft.

1.5 PROJECT SCHEDULE

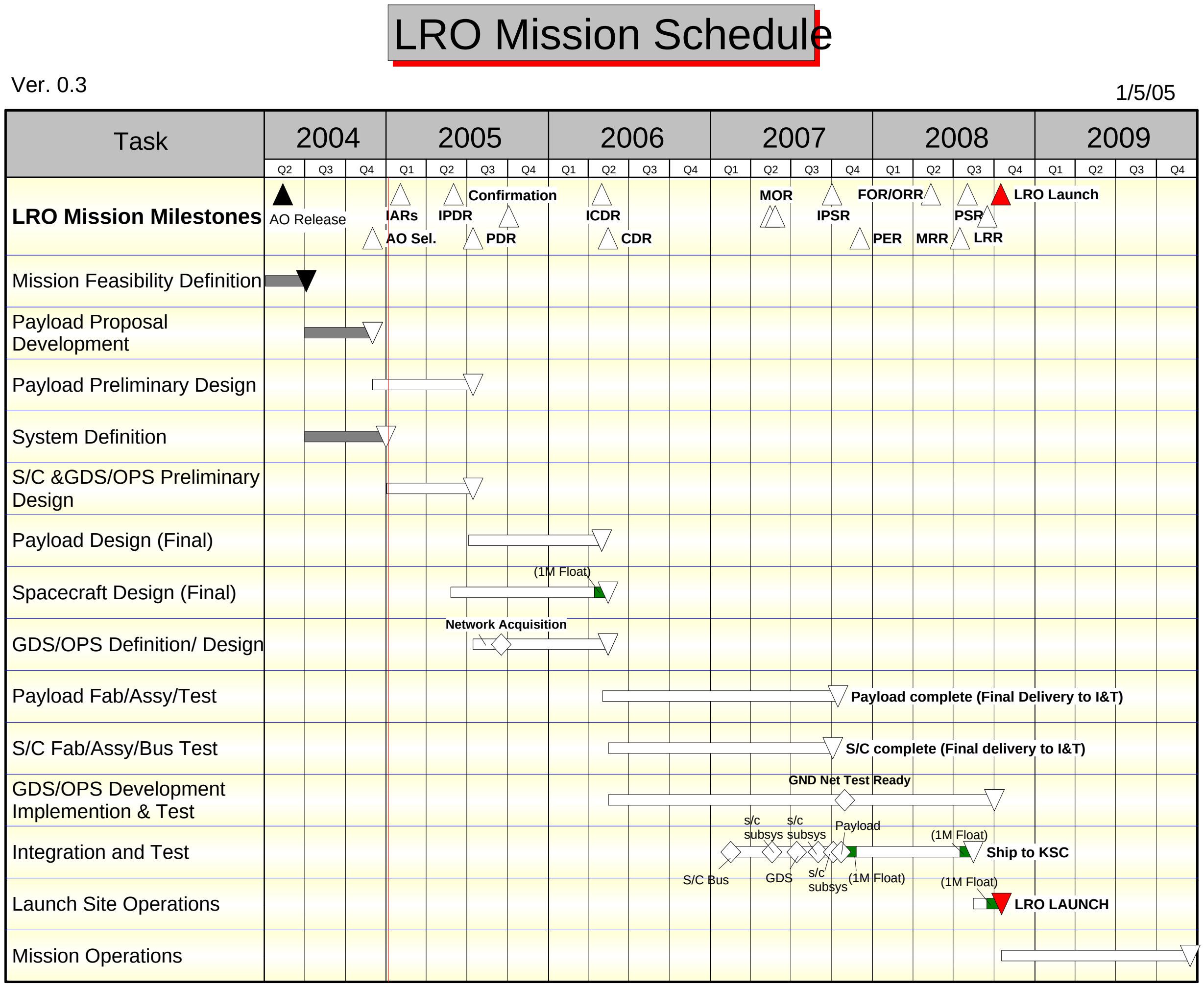


Figure 1-1 LRO Project Top-Level Schedule

2.0 ROLES AND RESPONSIBILITIES

This section describes the roles and responsibilities for personnel and organizations involved in LRO Mission Data archive, generation, validation, transfer, and distribution.

- LRO Project Office to provide overarching Data Management Plan and team coordination
- LRO Science Teams provide detailed product definitions, Interface Control Documents, Software Interface Specifications, Archive Management Plans, and science data production
- Planetary Data System (PDS) Team provide data archiving specifications, Integration & Test support, operational repository, and long term data archive and distribution

2.1 LRO Project Responsibilities

The LRO Project has overall responsibility for the acquisition, integration, launch, and operations of the LRO Observatory. The LRO Project is also responsible for distribution of data and associated information to LRO Science Operations Centers (SOCs).

The LRO Archives Working Group (LAWG) will coordinate the planning of the generation, validation, and release of PDS-compliant archives to the PDS. The LAWG is a subgroup of the LRO Project and reports to the Science Team Chair (LRO Project Scientist). LAWG membership includes the Principal Investigator, the Project Scientist, the Project Science Systems Engineer, the ICs, and project personnel selected to ensure that raw packets, engineering data sets, and documentation are included in archives. Representative PDS personnel will be liaison members of the LAWG. During the active mission the LAWG will provide the coordination needed to ensure that archives are assembled, validated, and delivered according to schedule.

2.2 LRO Instrument Team Responsibilities

The Principal Investigators and the Project Scientist ensure that archives are planned, validated, and delivered. The generation and validation of archives for release to the PDS will be performed by the individual instrument SOCs.

Each Principal Investigator, working with the Project Scientist, provides oversight of the archiving process for their respective instrument. They will review data analysis plans to assure timely and adequate analysis of spacecraft data and delivery of documented, complete data to the PDS.

2.3 Planetary Data System Responsibilities

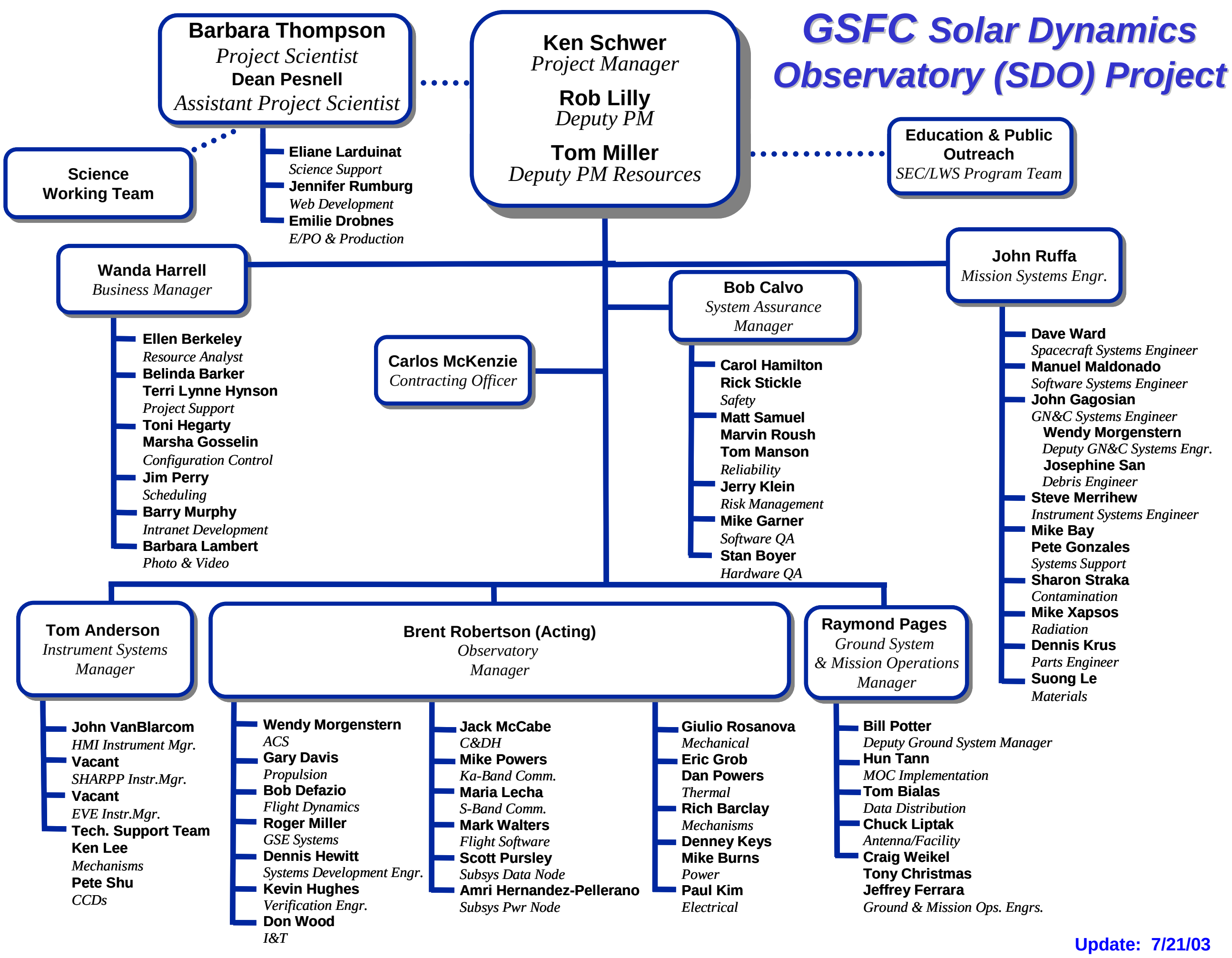
The PDS is the designated long term archive for the LRO Mission. The PDS will work with the LAWG to ensure that the LRO archives are compatible with PDS standards and formats. The PDS Geosciences Node will provide overall coordination of PDS activities for LRO. PDS Nodes will archive LRO data sets as designated in Table @x. Personnel from these PDS Nodes will be liaison LAWG Members.

The PDS will provide funds for generation, distribution, and maintenance of LRO archives for the NASA planetary science community once the LRO data have been delivered.

A Data Engineer from the PDS Central Node will work with the PDS Discipline Nodes involved with LRO Mission throughout the archive planning, generation, and validation phases.

LRO Data Source	**Archive PDS Discipline Node**
CRaTER	Planetary Plasma Interactions Node, UCLA
Diviner	Geosciences Node, Washington University
LAMP	Imaging Node, JPL/USGS
LEND	Geosciences Node, Washington University
LOLA	Geosciences Node, Washington University
LROC	Imaging Node, JPL/USGS
LRO MOC	NAIF Node, JPL

3.0 DATA Flow



3.1 Observatory Solid State Recorder (SSR)

Data collected by on-board instruments will be stored on the SSR as files. These files will be transmitted to the ground station as CCSDS packets. CCSDS File Delivery Protocol (CFDP) will be used to transfer science data files from the spacecraft SSR to the ground network.

3.2 Ground Network

The ground network control center performs data accountability and manages transfers to the ground network. Data is stored at the ground station and forwarded to the control center post-pass.

3.3 Mission Operations Center (MOC)

The MOC performs level 0 processing, transfers science data files to each SOC, and will archive 30 rolling days of science data in level 0 format. The MOC transfers spacecraft data to the SOCs as requested, and archives all spacecraft raw data for the life of the mission. The MOC is responsible for transferring all spacecraft data to PDS in SPICE format.

3.4 Instrument Science Operations Centers

Receives all raw/level 0 data, processes higher level science products, generates higher level products, and delivers all level 0 and higher data products to the Planetary Data System (PDS)

3.5 Planetary Data System

Archives and distributes all science data and ancillary products, level 0 and higher.

Documentation to be provided to PDS from LRO Project:
- High-level mission description (MISSION.CAT)
- High-level spacecraft description (INSTHOST.CAT)
- This data management plan

Documentation to be provided to PDS from SOCs:
- Software Interface Specifications
- IRDs/ICDs
- High-level instrument description (INST.CAT)
- High-level data set description (DATASET.CAT)
- Key personnel (PERSON.CAT)
- References (REF.CAT)
- Data processing production methodology and algorithms
- Instrument papers for journals

Appendix A. Abbreviations and Acronyms

Abbreviation/ Acronym	DEFINITION
CDR	Critical Design Review
CLE	Contamination Lead Engineer
DDS	Data Distribution System
EELV	Evolved Expendable Launch Vehicle
FMEA	Failure Modes and Effects Analysis
FOP	Flight Operations Plan
FOT	Flight Operations Team
FTA	Fault Tree Analysis
GN&C	Guidance, Navigation, and Control
GNCSE	GN&C Systems Engineer
GSE	Ground Support Equipment
ICD	Interface Control Document
ISE	Instrument Systems Engineer
ISM	Instrument Systems Manager
KSC	Kennedy Space Center
LRO	Lunar Reconnaissance Orbiter
ME	Materials Engineer
MOC	Missions Operations Center
MSE	Mission Systems Engineer
OSE	Operations Systems Engineer
PDL	Product Development Lead
PDR	Preliminary Design Review
PE	Parts Engineer
RBD	Reliability Block Diagram
RFA	Request for Action
RLE	Radiation Lead Engineer
RMB	Resource Management Board
RTT	Requirements Traceability and Tracking Lead
SCR	System Concept review
SDE	Systems Development Engineer
SDT	Science Definition Team Report
SEMP	Systems Engineering Management Plan
SOC	Science Operation Center
SRE	Systems Reliability Engineer
SRR	System Requirements Review
SSE	Spacecraft Systems Engineer
SWSE	Software Systems Engineer
