Lunar Reconnaissance Orbiter
Lunar Orbiter Laser Altimeter
Archive Volume
Software Interface Specification

Version 2.6

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SIGNATURE PAGE

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TABLES AND FIGURES

DOCUMENT CHANGE LOG

Change	Date	Affected Portions
Ward's suggested changes adopted, red text gone.	3/24/08	acronyms, all sections
Revisions by S. Slavney	5/19/08	1.2, 1.3, 2.3, 2.4, 2.5, 2.7, 2.9, 3.1.3, 4.1, 4.2, 4.4, 4.5 revised. BROWSE and EXTRAS directory sections deleted.
Revisions to product descriptions	8/14/08	3.16
Added BROWSE description	10/22/08	2.10
Added description of INDEX table columns	10/26/08	2.3, 6
Added Signature Page	10/26/08	ii
Version updated to October 22, 2008 Version 2	10/26/08	1.3
Section 2.1, second sentence, “are”, removed	10/26/08	2.1
Section 2.11, ISO 9660 standards conformance	10/26/08	2.11
Additions to Applicable Documents	10/26/08	1.3, 3.1.3
Volume ID clarified	10/26/08	4.5
Reference radius choices clarified	10/26/08	3.1.6
Table headings added	10/26/08	all
Table entries are punctuated if sentences.	10/26/08	all
Column for resolution date added to TBD items	11/17/08	v
Description of the PDS NAIF Node and SPICE	11/17/08	vi, 2.9
Figures 1 and 2 - DEM subdivisions added	11/17/08	3.1.6
INDEX table column descriptions clarified	11/17/08	6.1
Explanation of relationships with radio science	11/17/08	1.4
Revised filespecs of EDR, RDR, GDR polar	08/28/09	2.2, Table 13
Edited for readability, kj	02/19/10	All sections
JPEG2000 format for GDR products adopted	02/22/10	
Product subdirectories revised	09/16/10	
LOLA_GDR product and tiling specs revised	11/10/10	Section 3.1.6, Table 12
Version and filename updates	12/10/10	All
Updated, added SLDEM, FLOAT_IMG, LOLA_RADR – k jha	12/22/15	All
Updated to reflect actual contents of archive – SHS	1/12/16	All
Updated GEOMETRY. SOFTWARE moved to EXTRAS. Renamed instrument kernel file – k jha	02/23/16	2.8, 2.10

TBD ITEMS

Section	Description	Resolution Date

ACRONYMS AND ABBREVIATIONS

ASCII	American Standard Code for Information Interchange
DVD-ROM	Compact Disk or Digital Video Disk – Read-Only Memory
EDR	Experiment Data Record
GB	Giga Byte
GDR	Gridded Data Record, as elevation with respect to a sphere
GSFC	Goddard Space Flight Center
HTML	HyperText Markup Language
ILRS	International Laser Ranging Service
ISO	International Standards Organization 9660/UDF standards
JPEG	Joint Photographic Experts Group image format
JP2	JPEG2000 standard image format suffix
JPL	Jet Propulsion Laboratory
LOLA	Lunar Orbiter Laser Altimeter
LRO	Lunar Reconnaissance Orbiter
MB	Mega Byte
NAIF	Navigation and Ancillary Information Facility of the PDS
NSSDC	National Space Science Data Center
PDF	Portable Document Format
PDS	Planetary Data System
PNG	Portable Network Graphics image format
RADR	Reduced Albedo Data Record
RDR	Reduced Data Record
SHADR	Spherical Harmonic ASCII Data Record
SIS	Software Interface Specification
SLDEM	Selene-LOLA Digital Elevation Model
SOC	Science Operations Center
TBD	To Be Determined
URL	Universal Resource Locator
UTC	Coordinated Universal Time

GLOSSARY

Archive – An archive consists of one or more data sets along with all the documentation and ancillary information needed to understand and use the data. An archive is a logical construct independent of the medium on which it is stored.

Archive Volume, Archive Volume Set – A volume is a unit of media on which data products are stored; for example, one ISO 9660 CD-ROM or DVD-ROM (Applicable document #9). An *archive volume* is a volume containing all or part of an archive; that is, data products plus documentation and ancillary files. When an archive spans multiple volumes, they are called an *archive volume set*. Usually the documentation and some ancillary files are repeated on each volume of the set, so that a single volume can be used alone.

Catalog Information – Descriptive information about a data set (e.g. mission description, spacecraft description, instrument description), expressed in Object Description Language (ODL) suitable for loading into a PDS catalog.

Data Product – A labeled grouping of data resulting from a scientific observation, usually stored in one file. A corresponding product label identifies, describes, and defines the structure of the data. An example of a data product is a planetary image, a spectrum table, or a time-series table.

Data Set – An accumulation of data products. A data set together with supporting documentation and ancillary files is an archive.

Digital Elevation Model – A raster map of height with respect to lunar center of mass. The elevation may be shape values (absolute radii) or relative to a sphere of constant radius.

Profile – A time-ordered set of altimetry and allied data.

SPICE – An information system maintained by the PDS NAIF Node to assist scientists in planning and interpreting scientific observations from space-based instruments.

Standard Data Product – A data product generated in a predefined way using well-understood procedures, processed in "pipeline" fashion. (Data products that are generated in a nonstandard way are sometimes called *special data products*.)

1. Introduction

1.1. Purpose and Scope

This Software Interface Specification is intended to be used by those who wish to understand the format and content of the Lunar Reconnaissance Orbiter (LRO) Lunar Orbiter Laser Altimeter (LOLA) Archive. Typically, these individuals are software engineers, data analysts, or planetary scientists.

The specifications in this document apply to all LOLA standard product archive volumes that are generated by the LOLA investigation for the LRO Project.

Table 1. LOLA standard Data Product Datasets

Product Type	Data Set ID	Description
LOLA_EDR	LRO-L-LOLA-2-EDR-V1.0	Raw altimetry data
LOLA_RDR	LRO-L-LOLA-3-RDR-V1.0	Calibrated geolocated altimetry data
LOLA_RADR	LRO-L-LOLA-3-RADR-V1.0	Calibrated, geolocated active radiometry data
LOLA_GDR	LRO-L-LOLA-4-GDR-V1.0	Gridded (raster) digital elevation and related models
LOLA_SHADR	LRO-L-LOLA-5-SHADR-V1.0	Spherical harmonics gravity/topography models
SLDEM2015	LRO-L-LOLA-4-GDR-V1.0	Gridded LOLA data co-registered with SELENE's Terrain Camera data

1.2. Content Overview

This Software Interface Specification (SIS) describes the format, content, and generation of the LRO LOLA Instrument Data Archive. The Archive Volume is comprised of raw telemetry, calibrated, reduced and resampled, and processed data. RDR and higher level data are continually reprocessed with higher accuracy during the course of the LRO mission, and the updated versions logically supersede earlier versions. Such data include gridded data and spherical harmonic models, each of which are based on the accumulated data as of the close of the corresponding production cycle, approximately quarterly. LOLA data products are generated by the LOLA Science Operations Center (SOC) at GSFC. Section 2, Archive Volume Generation, describes the procedure for transferring data products to archive media. Section 3, Archive Volume Contents, describes the structure of the archive volumes and the contents of each file. Section 4, Archive Volume Format, describes the file formats used on the archive volumes. Finally, Section 5, Support Staff and Cognizant Persons, lists the individuals responsible for generating the archive volumes.

1.3. Applicable Documents and Constraints

This Archive Volume SIS is intended to be consistent with the following documents:

1. Lunar Reconnaissance Orbiter Project Data Management and Archive Plan, 431-PLAN-00182.
1. Lunar Reconnaissance Orbiter Lunar Orbiter Laser Altimeter Experiment Data Record Software Interface Specification (LOLA EDRSIS) V2.4, August 28, 2009.
2. LOLA Science Operations Center Requirements Document, Revision B, October 25, 2006.
3. LOLA Instrument Team Data Management and Archive Plan, Aug. 31, 2006.
4. Memorandum of Agreement for Establishment of the LRO LOLA Data Node Between the PDS Geosciences Node, Washington University, St. Louis, Missouri, and the Lunar Reconnaissance

Orbiter (LRO) LOLA Instrument Team, Goddard Space Flight Center, Greenbelt, Maryland, October 27, 2006.
5. LRO LOLA Science Team and PDS Geosciences Node Interface Control Document, October 9, 2006.
6. *Planetary Data System Archive Preparation Guide*, August 29, 2006, Version 1.1, JPL D-31224.
7. *Planetary Data System Standards Reference*, March 20, 2006, Version 3.7. JPL D-7669, Part 2.
8. ISO 9660-1988, Information Processing - Volume and File Structure of CD-ROM for Information Exchange, April 15, 1988.
9. *A Standardized Lunar Coordinate System for the Lunar Reconnaissance Orbiter*, LRO Project White Paper, 451-SCI-000958, Version 3, January 30, 2008.
10. Lunar Reconnaissance Orbiter Lunar Orbiter Laser Altimeter Reduced Data Record and Derived Products Software Interface Specification (RDRSIS), V2.53, September 16, 2010.

1.4. Relationships with Other Interfaces

The LOLA instrument is a component of the Laser Ranging system on board LRO. This Archive Volume SIS could be affected by changes to the design of the LRO Data Management System. The LRO radio tracking data are generated by the LRO Ground Data System, but there is no formal Radio Science investigation. These data are received by the LOLA Science Operations Center and are being archived separately from the LOLA Measurement Investigation. The Laser Ranging data will be archived as part of a Radio Science PDS archive on a best-efforts basis, and will also be maintained by the ILRS through the Crustal Dynamics Data Information System.

2. Archive Volume Contents

This section describes the contents of the LOLA Archive volumes, including the file names, file contents, file types, and organization responsible for providing the files.

2.1. Root Directory Contents

Files in the ROOT Directory include an overview of the archive, a description of the volume for the PDS Catalog, and a list of errata or comments about the archive. The following files and directories are contained in the ROOT Directory.

Table 2. Description of files in ROOT Directory

File Name	File Contents	File Provided By
AAREADME.TXT	Volume content and format information	LOLA Instrument Team
ERRATA.TXT	A cumulative listing of comments and updates concerning all archive volumes published to date	LOLA SOC
VOLDESC.CAT	A description of the contents of this volume in a PDS format readable by both humans and computers	LOLA SOC
/BROWSE	Images and hyper/text files related to DATA	LOLA SOC
/CATALOG	Descriptions of the data set, instruments, spacecraft, and mission as found in the PDS Catalog	LOLA SOC and Geosciences
/CALIB	Calibration documents, tables, notes	LOLA SOC
/DATA	Directories for standard product types	LOLA SOC
/DOCUMENT	Software interface specification files and labels	LOLA SOC
/EXTRAS	Tools and useful “value-added” context material such as Celestia textures, not crucial to understanding the dataset	LOLA SOC
/GEOMETRY	Instrument orientation with respect to spacecraft	LOLA SOC
/INDEX	Files provided to help the user locate products on this archive volume and on previously released volumes in the archive	Geosciences
/LABEL	Descriptions of data file formats, referenced by PDS labels	LOLA SOC

2.2. DATA Directory Contents and Naming

Under the DATA directory there is a separate subdirectory for each type of product. The subdirectories may include one or more of the following: LOLA_EDR, LOLA_RDR, LOLA_RADR, LOLA_GDR, LOLA_SHADR, and SLDEM2015. The EDR is the data produced by the instrument, in a form as close as possible to the files recorded on the spacecraft. The RDR data is calibrated, edited, and geolocated in a reversible manner. The RADR data are along-track profiles that contain normal albedo, the radiance of the Moon at zero phase angle. The GDR is a dataset resampled at uniform intervals, in both cylindrical and polar projections. The SHADR is a set of spherical harmonic coefficients describing the lunar shape, selenopotential reference surface, albedo, and static gravitational potential. SLDEM2015 is a gridded dataset in cylindrical projection between 60S and 60N for all longitudes, in which LOLA data are co-registered with Kaguya Terrain Camera data.

The LOLA_EDR, LOLA_RDR, and LOLA_RADR directories are subdivided into LRO_PP_NN, where PP refers to the first two letters of mission phase (CO = Commissioning,

NO = Nominal, SM = Science Mission, ES = Extended Science Mission or Second Extended Science Mission), and NN refers to the current monthly orbital cycle, ending with Station Keeping Maneuvers. The RADR directories are initially subdivided by the laser that was firing at the time, laser1 or laser2.

Typical filepaths for the EDR product is

/DATA/LOLA_EDR/LRO_NO_NN/LOLAEDRYYDDDHHMM.DAT.

Likewise the LOLA_RDR directory is subdivided and a typical file path for the RDR product is

/DATA/LOLA_RDR/LRO_NO_NN/LOLARDR_YYDDDHHMM.DAT.

This schematic shows an example of the nesting of directories for an EDR volume for data acquired beginning November 20, 2009 through December 17, 2009, ending at the fourth stationkeeping maneuver.

<Volume Root>

DATA|

| LOLA_EDR

| LRO_NO_03

|<LOLAEDR09dddhhmm.DAT files>

...

This schematic shows an example of the nesting of directories for the RDR, RADR, GDR, SHADR, and SLDEM data. For the gridded data products, <filespecs> are pixels per degree in CYLINDRICAL and meters per pixel in POLAR. Tiles are denoted by latitude range followed by longitude range, i.e., LDEM_512_00N_45N_180_360.IMG, or LDEM_75N_120M.IMG. The FLOAT_IMG floating point format is additionally provided for additional precision where file sizes remain reasonable. The PA subdirectories under LOLA_GDR and LOLA_SHADR contain a shape map and spherical harmonic model of the Moon using the dynamically defined Principal Axis coordinate system for consistency with other lunar gravity spherical harmonic models, including that acquired by the GRAIL mission.

<Volume Root>

DATA|

|LOLA_GDR

|POLAR

|FLOAT_IMG

|<LDEM_[<filespecs>]_FLOAT.IMG files>

|IMG

| <LDEM_[<filespecs>].IMG files>

|JP2

| <LDEM_[<filespecs>].JP2 files

|LOLA_GDR

|CYLINDRICAL

|FLOAT_IMG

|<LDEM_[<filespecs>]_FLOAT.IMG files>

|IMG

| <LDEM_[<filespecs>].IMG files>

|JP2

| <LDEM_[<filespecs>].JP2 files

|PA

| <LDEM_[<filespecs>]_PA.IMG files>

|LOLA_RDR

| LRO_NO_03

|<LOLARDR_yydddhhmm.DAT files>

|LOLA_RADR

|LASER1

|LRO_[mission phase]_[orbital cycle]

|LOLARADR_yydddhhmm.TAB

|POLARPATCH_[NP or SP]

|LRO_[mission_phase]_[orbital cycle]

|LOLARADR_yydddhhmm_[NP or SP].TAB

|LASER2

|LRO_[mission phase]_[orbital cycle]

|LOLARADR_yydddhhmm.TAB

|LOLA_SHADR

|LRO_LTM[model number]_[degree and order]_SHA.TAB

|PA

|LRO_LTM[model number]_PA_[degree and order]_SHA.TAB

|SLDEM2015

|GLOBAL

|FLOAT_IMG

|<SLDEM_[<filespecs_lat_lon>]_FLOAT.IMG files>

|JP2

| SLDEM_[<filespecs>].JP2 files

|TILES

|FLOAT_IMG

|<SLDEM_[<filespecs_lat_lon>]_FLOAT.IMG files>

|JP2

| SLDEM_[<filespecs>].JP2 files

Each data file is accompanied by a PDS label file with the same name. JP2 products additionally have an accompanying XML file for use with certain mapping software; see the file JP2INFO.TXT in the DOCUMENT directory.

2.3. INDEX Directory Contents

Files in the INDEX Directory are provided to help the user locate products on this archive volume and on previously released volumes in the archive. The following files are contained in the INDEX Directory.

Table 3. Description of files in INDEX Directory

File Name	File Contents	File Provided By
EDRINDEX.LBL	A PDS detached label that describes EDRINDEX.TAB	LOLA SOC
EDRINDEX.TAB	A table listing all EDR data products in the archive	LOLA SOC
EDRINDEX.LBL	A PDS detached label that describes EDRINDEX.TAB	LOLA SOC
EDRINDEX.TAB	A table listing all EDR data products in the archive	LOLA SOC
RDRINDEX.LBL	A PDS detached label that describes RDRINDEX.TAB	LOLA SOC
RDRINDEX.TAB	A table listing all RDR, RADR, GDR, SHADR, and SLDEM data products in the archive	LOLA SOC
INDXINFO.TXT	A description of the contents of this directory	LOLA SOC

2.4. DOCUMENT Directory Contents

The DOCUMENT Directory contains documentation to help the user understand and use the archive data. The following files are contained in the DOCUMENT Directory.

Table 4. Description of files in DOCUMENT Directory

File Name	File Contents	File Provided By
ARCHSIS.HTM	The Archive Volume SIS (this document) as hypertext	LOLA SOC
ARCHSIS.LBL	A PDS detached label that describes both ARCHSIS.HTM and ARCHSIS.PDF	LOLA SOC
ARCHSIS.PDF	The Archive Volume SIS (this document) as a PDF file	LOLA SOC
ARCHSIS_*.JPG	Images used in ARCHSIS.HTM	LOLA SOC
DOCINFO.TXT	A description of the contents of this directory	LOLA SOC
EDRSIS.HTM	The EDR Data Product SIS as hypertext	LOLA SOC

EDRSIS.LBL	A detached label that describes both EDRSIS.HTM and EDRSIS.PDF	LOLA SOC
EDRSIS.HTM	The EDR Data Product SIS as hypertext	LOLA SOC
EDRSIS.LBL	A detached label that describes both EDRSIS.HTM and EDRSIS.PDF	LOLA SOC
EDRSIS.PDF	The EDR Data Product SIS as a PDF file	LOLA SOC
EDRSIS_*.JPG	Images used in EDRSIS.HTM	LOLA SOC
JP2INFO.TXT	Description of JP2 versions of GDR images and how to use them	LOLA SOC
MISSION_PHASE_TIMES.TAB	Table of start and stop times for LRO orbital mission phases	LOLA SOC
RDRSIS.HTM	The RDR Data Product SIS as hypertext	LOLA SOC
JP2INFO.TXT	Description of JP2 versions of GDR images and how to use them	LOLA SOC
MISSION_PHASE_TIMES.TAB	Table of start and stop times for LRO orbital mission phases	LOLA SOC
RDRSIS.HTM	The RDR Data Product SIS as hypertext	LOLA SOC
RDRSIS.LBL	A detached label that describes both RDRSIS.HTM and RDRSIS.PDF	LOLA SOC
RDRSIS.PDF	The RDR Data Product SIS as a pdf file	LOLA SOC
RDRSIS_*.JPG	Images used in RDRSIS.HTM	LOLA SOC
SLDEM2015.TXT	Description of SLDEM data	LOLA SOC

2.5. CATALOG Directory Contents

The files in the CATALOG Directory provide a top-level understanding of the mission, spacecraft, instruments, and data sets. The files in this directory are coordinated with the PDS data engineer, who is responsible for loading them into the PDS catalog. The following files are found in the CATALOG Directory.

Table 5. Description of files in CATALOG Directory

File Name	File Contents	File Provided By
CATINFO.TXT	A description of the contents of this directory	LOLA SOC
DSMAP.CAT	Map projection information for simple cylindrical projection	LOLA SOC
DSMAP_POLAR.CAT	Map projection information for polar stereographic projection	LOLA SOC
EDR_DS.CAT	EDR data set information for the PDS catalog	LOLA SOC
EDR_VOLDESC.CAT	EDR (raw) altimetry volume catalog (also found in root directory of EDR archive volume)	LOLA SOC
GDR_DS.CAT	Gridded Data Record information for the PDS (including SLDEM2015)	LOLA SOC
INSTHOST.CAT	Instrument host (i.e., spacecraft) information for the PDS	LRO Project
LOLAINST.CAT	Instrument information for the PDS catalog	LOLA SOC
MISSION.CAT	Mission information for the PDS catalog	LRO Project
PERSON.CAT	Personnel information for the PDS catalog (Team and PDS personnel responsible for generating the archive)	LOLA SOC
RADR_DS.CAT	RADR dataset information for the PDS	LOLA SOC
RDR_DS.CAT	RDR dataset information for the PDS	LOLA SOC

RDR_VOLDESC.CAT	RDR, RADR, GDR, SLDEM, and SHADR Volume catalog (also found in root directory of RDR archive volume)	LOLA SOC
REF.CAT	References mentioned in other *.CAT files	LOLA SOC
SHADR_DS.CAT	Spherical Harmonic Data Record information for the PDS	LOLA SOC

2.6. LABEL Directory Contents

The LABEL Directory contains files that describe data format and organization. These files are referred to in the PDS labels that accompany the data products. They are "include" files that are intended to be parsed as if they were part of the PDS labels that refer to them. The following files are contained in the LABEL Directory.

Table 6. Description of files in LABEL Directory

File Name	File Contents	File Provided By
LABINFO.TXT	A description of the contents of this directory	LOLA SOC
LOLAEDR.FMT	LOLA science telemetry 1-Hz data format	LOLA SOC
LOLAHKCT.FMT	LOLA housekeeping telemetry container for 28 Hz data	LOLA SOC
LOLARADR.FMT	LOLA active radiometry data record format	LOLA SOC
LOLARDR.FMT	LOLA reduced science data record format for 28 Hz data	LOLA SOC
LOLASCCT.FMT	LOLA science telemetry container for 28 Hz data	LOLA SOC

2.7. CALIB Directory Contents

The CALIB Directory contains calibration files used to process the data products, or calibration data needed to use the data products. The following files are contained in the CALIB Directory.

Table 7. Description of files in CALIB Directory

File Name	File Contents	File Provided By
CALINFO.TXT	A description of the contents of this directory	LOLA SOC
CALIBRPT.LBL	A PDS detached label that describes both CALIBRPT.HTM and CALIBRPT.PDF	LOLA SOC
CALIBRPT.PDF	Description of instrument and data calibration performed by LOLA team	LOLA SOC
CALIBRPT.HTM	HTML version of instrument and data calibration	LOLA SOC
CALIBRPT_FILES	Directory of images used in CALIBRPT.HTM	LOLA SOC

2.8. GEOMETRY Directory Contents

The GEOMETRY Directory contains files needed to understand observation geometry. Geometry information incorporating refined analyses of the instrument and spacecraft geometry are produced in CK, SPK, and SCLK formats. The C-kernel (CK) system is the component of SPICE concerned with attitude of spacecraft structures or instruments. The SCLK system is the component of SPICE concerned with spacecraft clock correlation data. These are archived separately via the NAIF Node and can be referenced at http://naif.jpl.nasa.gov/pub/naif/pds/data/lro-l-spice-6-v1.0

The SPK system is the component of SPICE concerned with ephemeris data. The LOLA SPKs are precision orbits calculated using a GRAIL-based gravity field, and are archived as part of the Radio Science data archive. These can be found at http://pds-geosciences.wustl.edu/lro/lro-l-rss-1-tracking-v1/lrors_0001/data/spk

The boresight vector is used to geolocate returns measured by the instrument. The unit boresight vectors used for the initial LOLA release were revised (10/06/2010) by a few hundredths of a degree to reflect in-flight improvements in knowledge.

The most recent revision (6/16/2014) implements a separate set of boresight vectors for day and night to account for misalignment of the laser beam expander caused by the contraction of thermal blankets facing the cold night side of the Moon. The LOLA geometry assumes an offset of the laser vector origin (X, Y, Z) = (2.046, 0.961, 0.523) in meters with respect to the spacecraft frame. The precision orbits determine the spacecraft center of mass, relative to which the laser vector origin is (X, Y, Z) = (1.0, 1.14, 0.55) meters. The unit vector of the laser range relative to the SPICE frame LRO_SC (-85000) is given by the time-dependent data statements for each of the five beams. The values used for different data releases are given in this directory in the file BORESIGHT.TXT

Table 8. Description of files in GEOMETRY Directory

File Name	File Contents	File Provided By
GEOMINFO.TXT	A description of the contents of this directory	LOLA SOC
LRO_LOLA_V01.TI	Description of LOLA instrument frames used by SPICE	LOLA SOC
BORESIGHT.TXT	Boresight vector values used for geolocation	LOLA SOC

2.9. BROWSE Directory Contents

The BROWSE Directory contains reduced-size, easily viewed versions of data products to be used to help identify products of interest. The following files are contained in the BROWSE Directory.

Table 9. Description of files in BROWSE directory

File Name	File Contents	File Provided By
BROWINFO.TXT	A description of the contents of this directory	LOLA SOC
BROWINFO.HTM	HTML File linking browse images to products	LOLA SOC
BROWINFO.LBL	PDS label for BROWINFO.TXT and BROWINFO.HTM	LOLA SOC
LOLA_RDR	Directory containing images of topographic profiles organized by mission phases	LOLA SOC
LOLA_GDR	Directory containing images of gridded products	LOLA SOC

The browse information consists of images of profiles for the RDR data products, while that for the GDR products are thumbnail images of topographic shaded relief or ancillary data. Either PNG, GIF or JPEG formats are employed, with images linked to an HTML-based table.

2.10. EXTRAS Directory Contents

The EXTRAS Directory contains documentation, utility programs, or other materials that the user may find helpful, but that are beyond the scope of the required elements of the archive.

There are no restrictions on the contents and organization of this directory other than conformance to ISO-9660/UDF standards. The EXTRAS Directory is intended for "value-added" material, handy to have but not crucial for understanding the data. The following files are contained in the EXTRAS Directory.

Table 10. Description of files in EXTRAS directory

File Name	File Contents	File Provided By
EXTRINFO.TXT	A description of the contents of this directory	LOLA SOC
INDEX.HTML	HTML File linking ancillary documentation and utilities	LOLA SOC
CELESTIA	LOLA data textures for use with Celestia 3D simulation software	LOLA SOC
FRACTAL	Maps of coefficients indicating lunar roughness	LOLA SOC
GEOID	Maps of lunar geoid height derived from LOLA data	LOLA SOC
ILLUMINATION	Maps of solar illumination, permanently shadowed regions, solid angle of the sky as visible from the lunar surface, and average visibility of the Earth from the lunar surface	LOLA SOC
SLDEM2015	A redundant version of the files under DATA, to be consistent with location given in published paper	LOLA SOC
SOFTWARE	Software for viewing or extracting data	LOLA SOC

3. Archive Volume Format

This section describes the format of LOLA Archive Volumes. Data that comprise the Archive is formatted in accordance with Planetary Data System specifications [Applicable Document 8].

3.1. File Formats

The following section describes file formats for the kinds of files contained on archive volumes. For more information, see the *PDS Archive Preparation Guide* §1.3.

3.1.1. Document File Format

Document files with the .CAT or .TXT suffix exist in the ROOT, INDEX, CATALOG, DOCUMENT, and LABEL directories. They are ASCII files that may have embedded PDS labels. Lines in such files end with a carriage return character (ASCII 13) and a line feed character (ASCII 10). This allows the files to be readable under various operating systems.

Documents in the DOCUMENT and CALIB directory may contain formatting and figures that cannot be rendered as ASCII text. Therefore each document is given in two formats, hypertext and PDF. The hypertext file contains ASCII text plus hypertext markup language (HTML) commands that enable it to be viewed in a Web browser such as Mozilla (the successor to Mosaic and Netscape), Safari (the browser for Mac OS X), or IE7 (the default browser for Microsoft Corporation products). The hypertext file may be accompanied by ancillary files such as images and style sheets that are incorporated into the document by the Web browser for the convenience of the user. The second format, PDF (Portable Document Format) is a proprietary format of Adobe Systems Incorporated that is frequently used for distributing documents. Adobe offers free software, Acrobat Reader, for viewing PDF files.

3.1.2. Tabular File Format

Tabular files (.TAB suffix) exist in the INDEX directory. They are ASCII files formatted for direct reading into many database management systems on various computers. All fields are separated by commas, and character fields are enclosed in double quotation marks ("). (Character fields are padded with spaces to keep quotation marks in the same columns of successive records.) Character fields are left justified, and numeric fields are right justified. The "start byte" and "bytes" values listed in the labels do not include the commas between fields or the quotation marks surrounding character fields. The records are of fixed length, and the last two bytes of each record contain the ASCII carriage return and line feed characters. This allows a table to be treated as a fixed length record file on computers that support this file type and as a text file with embedded line delimiters on those that don't.

All tabular files are described by PDS labels, either embedded at the beginning of the file or detached. If detached, the PDS label file has the same name as the data file it describes, with the extension .LBL; for example, the file EDRINDEX.TAB is accompanied by the detached label file EDRINDEX.LBL in the same directory.

3.1.3. PDS Label Format

All data files in the archive have PDS labels, either embedded at the beginning of the file or, in the case of the EDR data product, detached in a separate file. For examples of PDS labels for each type of data product, see the Data Product SISs [Applicable Documents 2 and 11].

A PDS label, whether embedded or detached from its associated file, consists of lines of ASCII text in the form of keyword = value statements that provide descriptive information about the data file. The label is intended to be readable both by humans and by software. Details of the syntax and semantics of PDS labels can be found in the PDS Standards Reference (Applicable Document 8), and definitions of the keywords used in the label can be found by using the PDS Data Dictionary Lookup web service at URL https://pds.nasa.gov/tools/dd-search/.

Lines of text in detached labels end with a carriage return character (ASCII 13) and a line feed character (ASCII 10). This allows the files to be read under various operating systems.

3.1.4. Catalog File Format

Catalog files (suffix .CAT) exist in the Root and CATALOG directories. Like PDS labels, they are text files formatted as “keyword = value statements”. They contain descriptions of the data set, instrument, spacecraft, and mission, as well as personnel contact information and references to published literature. They are called Catalog Files because they are loaded into the PDS online catalog to make the information available to users searching for data.

3.1.5. Science Data File Formats

The LOLA EDR data products are in the form of binary time-ordered tables representing engineering telemetry and laser time-of-flight data in counts. Each file corresponds to a single file downloaded from the spacecraft solid-state recorder. The binary tables include columns with multi-byte integers in both most-significant-byte-first and least-significant-byte-first order, as well as nonstandard triplets representing 24-bit integers. One file contains approximately 5 minutes of engineering and science data, including Earth ranges from the Laser Ranging

experiment. Information about the format and content of the data products is given in the EDR Data Product SIS [Applicable Document 2].

The LOLA RDR data products are maintained in the form of binary time-ordered tables for ease of manipulation. All columns consist of 2-byte and 4-byte, signed or unsigned LSB integers that may be translated into ASCII tables for the end users by means of provided software in /EXTRAS/SOFTWARE. Each RDR product will be aggregated on orbital boundaries into a product name with extension ".DAT" and provided with a detached label with the same product name and an extension ".LBL". The detached label will reference Format files contained in the archive's LABEL directory.

The LOLA RADR data products are maintained in the form of ascii time-ordered tables. The LOLARADR.FMT file, found in the LABEL directory, specifies the format for each field in the data product. A detached label with the same product name and an extension ".LBL" is provided alongside each file.

The primary LOLA GDR data products consists of raster Digital Elevation Models (shape models)and Digital Elevation Counts (samples per pixel) as binary images with detached labels. Additional GDR products include slope and roughness grids, albedo grids, and elevation maps derived from the cross-registration of LOLA and Kaguya data (SLDEM grids). The file type of the GDR products is "IMG". The larger _FLOAT.IMG, in decimal format, is also provided for smaller grids. The JPEG2000 lossless compressed file format, with a file extension of "JP2", are also employed using Geospatial Data Abstraction Library headers (www.gdal.org). This format provides smaller file sizes and is compatible with many Geographical Information Systems. The global JP2 files have a projection center longitude of 0 degrees, following GIS practice, as distinct from the 0-360 convention used for the IMG products, as recommended by the LRO Project.

A pixel in the GDR product represents the mean value at the center of a region bounded by lines of constant longitude and latitude at integral numbers of degrees or fractions thereof, scaled and interpolated where necessary. The size of the products at higher resolutions requires that they be aggregated in subsets of global coverage. Global standard products use the Equirectangular map projection, also known as Simple Cylindrical, while the higher-resolution products afforded by dense polar coverage use the Polar Stereographic projection. Tiling is employed to limit the size of individual products to less than 2 GB to facilitate electronic data transfer. Binary elevation data consists of 16-bit integers, scaled by 0.5 meters to a dynamic range of ±16 km relative to datum. The resolution of equirectangular pixels is in powers of two pixels per degree of longitude and latitude. The resolution of polar projected pixels is in integral numbers of meters at a radius of 1737400 m, true at the pole. The pole is a point surrounded by the four central pixels, and the colatitude of a pixel at a distance r meters from the north pole is simply $2\ arctan\ (0.5\ r\ /\ 1737400)$. Anticipated tiles and product sizes are as follows, while tiling is shown in Figure 1.

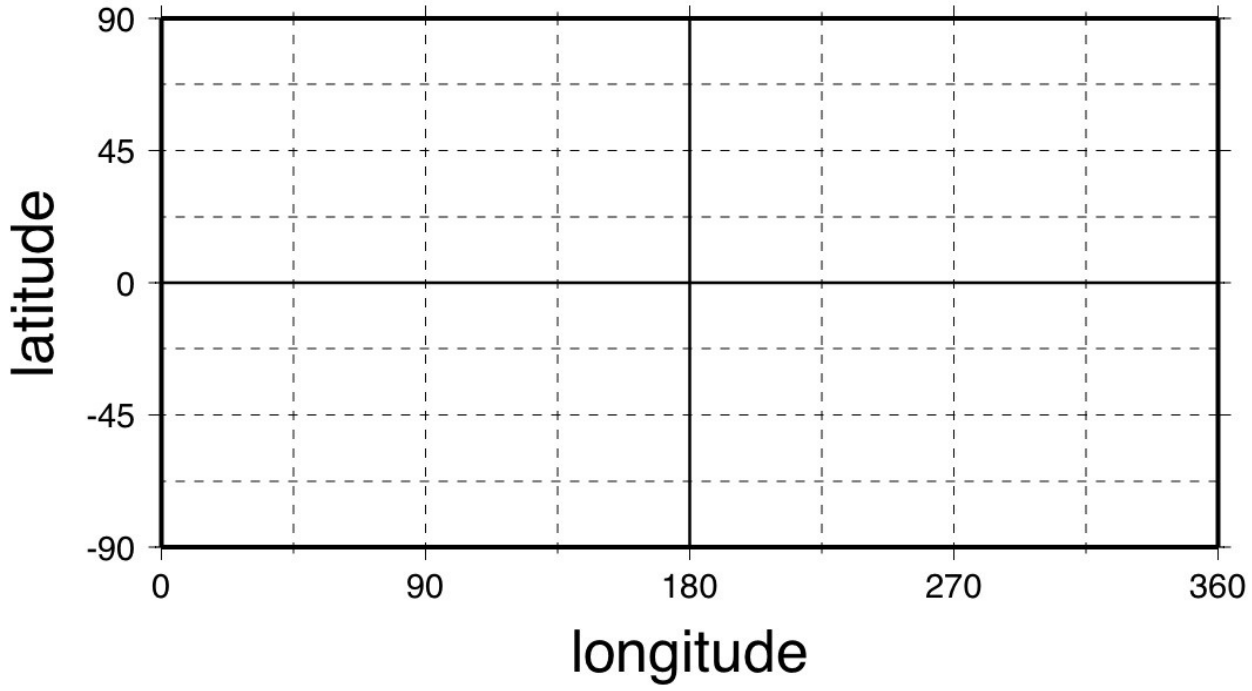
Table 11. Equirectangular map-projected digital elevation models

Product	Product Size	Pixel size	Number/size of tiles	bits per pixel
LDEM_4	2 MB	7.5808 km in latitude	Global, 0-360	16
LDEM_16	32 MB	1.895 km in latitude	Global, 0-360	16
LDEM_64	512 MB	0.4738 km in latitude	Global, 0-360	16

LDEM_128	2 GB	0.2369 km in latitude	Global, 0-360	16
LDEM_256	4x2GB	118.45 m in latitude	4 tiles, longitudes 0:180:360 by N/S	16
LDEM_512	16x2GB	59.225 m in latitude	longitudes 0:90:180:270:360 by 45° latitude bands	16
LDEM_1024	* 64x2GB	29.612 m in latitude	longitudes 0:45:90:135:180:225:270:315:360 by 22.5° latitude bands	16

Note: Product size is limited to 2GB for compatibility with most platforms. Geospatial products may be generated in larger sizes as special products.

Figure 1: Equirectangular map projection. Lines show notional tiling subdivisions of LDEM_256 (bold), LDEM_512 (fine), and LDEM_1024 (dashed).

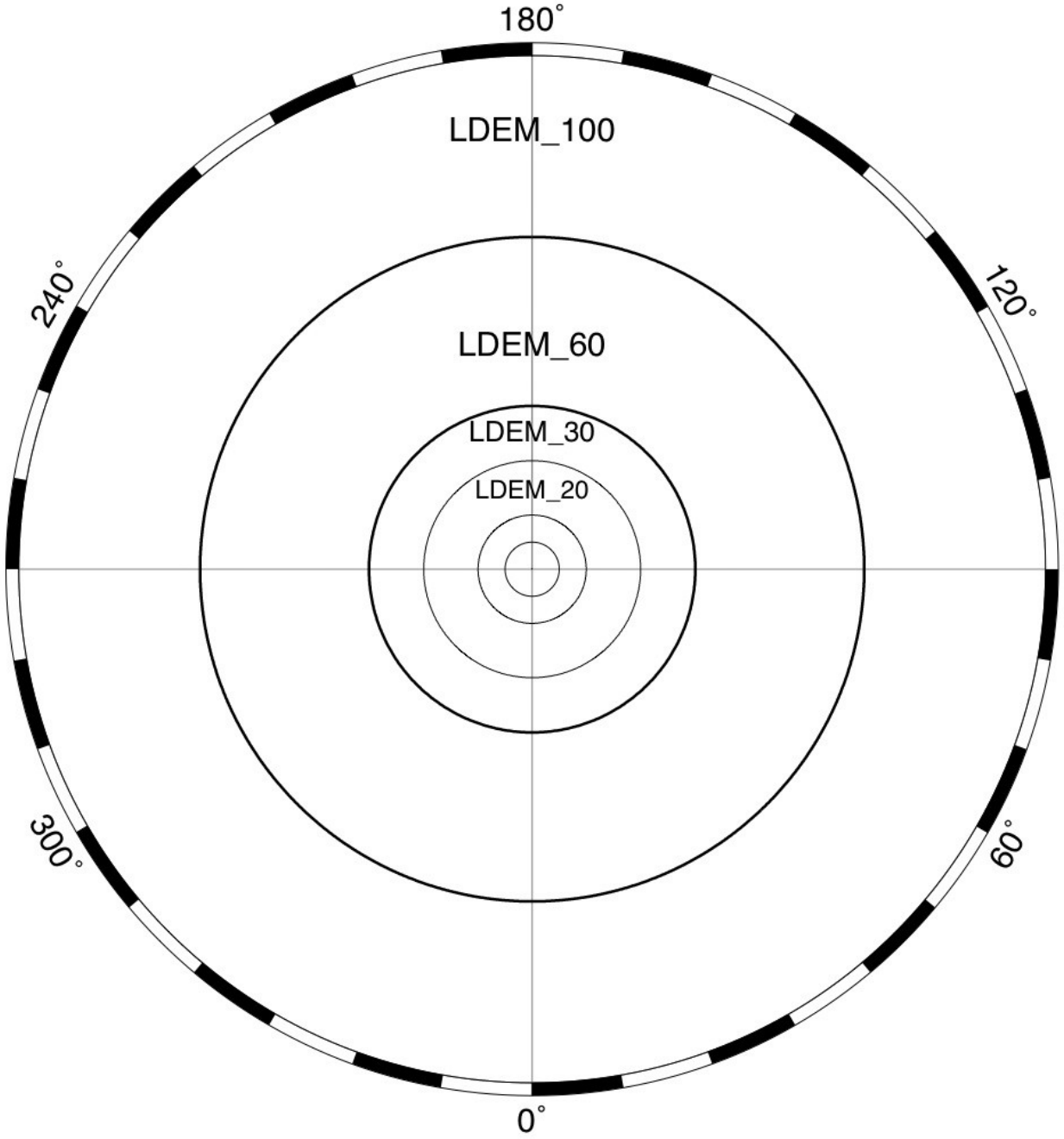


Polar stereographic projections are produced at latitudes from 45 degrees to the poles. These consist of a single image file at each pole, roughly 1.8 GB in size, as well as subsampled images, i.e. LDEM_75S_120M is 4x4 coarser than LDEM_75S_30M. Those products with * were not generated in earlier deliveries due to the lack of data density. They were generated at full resolution once data density permitted.

Table 12. Polar map-projected digital elevation models, N/S

Product	dimensions	Pixel size	Latitude range	bits per pixel
LDEM_45S_100M	28800x28800	100x100m	+/-45° to pole	16
***LDEM_60S_60M**	31040x31040	60x60 m	+/-60° to pole	16
LDEM_75S_30M	30496x30496	30x30 m	+/-75° to pole	16
***LDEM_80S_20M**	30400x30400	20x20 m	+/-80° to pole	16
LDEM_85S_10M	30336x30336	10x10 m	+/-85° to pole	16
***LDEM_87S_5M**	30336x30336	5x5 m	+/-87.5° to pole	16

Figure 2: Polar stereographic map projection from 45°N to pole. Circles show outlines of LDEMs at various resolutions (innermost circles enclose 10 and 5 meter DEMs).



Special map products are also generated to describe surface properties such as albedo, slope, and roughness, in formats consisting of a subset of the DEM products. Algorithms for producing these products depend on performance of the instrument, research and development. Ancillary special map products will be generated to show data density or interpolation quality.

The LOLA SHADR data products consist of ASCII tables, preceded by PDS labels. The form of these tables will be that of Comma-Separated Values. The tables will closely resemble that of the Lunar Prospector gravity archives. Spherical harmonic shape and bidirectional reflectance

models will complete the SHADR dataset. The gravity potential coefficients are customarily normalized so that the spherical harmonic functions each have unit mean variance on a sphere, in accordance with geophysical practice, and are further normalized to a reference equatorial radius of 1,738,000 meters. This choice of radius is for compatibility with legacy datasets, and with observation equations - "normal equations" - used in orbital and potential analysis that, for compact storage, are summed with respect to a particular radius. The derived potential coefficients may be transformed to any other choice of reference radius.

4. Archive Volume Generation

4.1. Data Transfer and Validation Methods

All LOLA products and labels are generated by the Lunar Orbiter Laser Altimeter Science Team at GSFC. The LOLA Team validates the products for scientific integrity in conjunction with other LRO instrument teams. The EDR products are checked for transmission errors and correctness of associated labels. The RDR products undergo editing steps and pipeline processing, with subsequent analysis to validate their measurement accuracy. The RDR products undergo monthly revisions after each orbit maintenance cycle. Standard methods are used to create the GDR and SHADR products, whose revisions are associated with that of the cumulative RDR dataset. The entire archive is hosted at the LOLA SOC as a Data Node of the PDS, per Applicable Document #6. According to the schedule set by the LRO Project, the LOLA Team makes a delivery of completed archive volumes to PDS every three months, beginning six months after the start of the mapping mission. The Geosciences Node validates sample EDR and RDR products and completed archive volumes for compliance with PDS standards. Delivery to PDS is performed in accordance with Applicable Document #6.

4.2. Data Product Sizes and Delivery Rates

Table 2 summarizes expected sizes and production rates for the LOLA EDR and RDR Standard Products, as well as estimates of the higher level product volumes.

Table 13. Standard Product Sizes and Delivery Rates

Product	Product Size	Production Rate	Expected Number of Products for Nominal Mission	Expected Total Data Volume for Nominal Mission
LOLA_EDR	23-24 MB	12.1-12.4 per day, average	4700	113 GB
LOLA_RDR	~50 MB	same	4700	235 GB
LOLA_GDR	<2 GB	monthly revisions of ~100 data products	100	200 GB
LOLA SHADR	5 MB	release at quarterly intervals	4	<1 GB

4.3. Interface Media Characteristics

All removable volumes in the LOLA Standard Product Archive, whether CD, DVD-ROM, or electronic archive, conform to ISO 9660 standards [ISO 9660, 1988].

4.4. Backup and Duplicates

Backup copies of LOLA EDR, RDR, RADR, SLDEM, GDR, and SHADR products will be stored at the LOLA Data Node at GSFC and at the Department of Earth, Atmospheric, and Planetary Sciences of the Massachusetts Institute of Technology until the final versions of products have been archived on physical media with the PDS. Duplicate copies of LOLA archive volumes will be stored on physical media at the PDS Geosciences Node and the National Space Science Data Center.

4.5. Labeling and Identification

There are two LOLA archive volumes. They will be identified by a unique VOLUME_ID formed according to the scheme LROLOL_dXXX where:

LRO is the mission ID

LOL is the instrument ID

d is the data set stored on the archive volume, where

d = 0 for EDR only;

d = 1 for RDR, RADR, GDR, SHADR, SLDEM, and special products.

Should it become necessary to rerelease the archives, the VOLUME_ID will be incremented. XXX represents an online volume of unlimited size. In the event that the PDS ever repackages the archive on smaller media units such as DVDs, the XXX is replaced by a volume sequence number starting with 001.

5. Support Staff and Cognizant Persons

David E. Smith, LOLA Principal Investigator, NASA Goddard Space Flight Center

Maria T. Zuber, LOLA Deputy P.I., Massachusetts Institute of Technology

Gregory A. Neumann, LOLA co-Investigator, NASA Goddard Space Flight Center

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Jennifer G. Ward, Mission Archivist, PDS Geosciences Node, Washington University, St. Louis, Missouri

6. Appendices

6.1. Contents of the RDRINDEX.LBL file

```
PDS_VERSION_ID       = PDS3
RECORD_TYPE          = FIXED_LENGTH
RECORD_BYTES         = 293
FILE_RECORDS         = 4637
^INDEX_TABLE         = "RDRINDEX.TAB"
VOLUME_ID            = LROLOL_1XXX
DATA_SET_ID          = "LRO-L-LOLA-3-RDR-V1.0"
MISSION_NAME         = "LUNAR RECONNAISSANCE ORBITER"
INSTRUMENT_NAME      = "LUNAR ORBITER LASER ALTIMETER"
DESCRIPTION          = "This index file lists information
   about each of the LRO LOLA RDR data products contained on
   this archive volume."

OBJECT               = INDEX_TABLE
  INDEX_TYPE         = SINGLE
  INTERCHANGE_FORMAT = ASCII
  ROWS               = 4637
  ROW_BYTES          = 293
  COLUMNS            = 13
  DESCRIPTION        = "
    This table contains the volume index of all data files on
    this volume.

    Each record of this index consists of comma delimited data
    columns followed by an ASCII carriage-return and line-feed.
    The ROW_BYTES value includes not only the lengths of
    the values themselves, but also any quotes, the commas, and
    the row terminating characters (carriage-return,line-feed).
    The BYTES value in each column definition includes only the
    value, not surrounding quotation marks or commas."

  OBJECT     = COLUMN
    NAME          = VOLUME_ID
    COLUMN_NUMBER = 1
    START_BYTE    = 2
    BYTES         = 12
    DATA_TYPE     = CHARACTER
    DESCRIPTION   = "The PDS VOLUME_ID: LROLOL_1XXX"
  END_OBJECT = COLUMN
```

```
OBJECT     = COLUMN
  NAME          = FILE_SPECIFICATION_NAME
  COLUMN_NUMBER = 2
  START_BYTE    = 17
  BYTES         = 57
  DATA_TYPE     = CHARACTER
  DESCRIPTION   = "Fully qualified name of the data file, relative to
    the volume root directory"
END_OBJECT = COLUMN
/* Note that the file specification originates at the root, so no */
/* logical volume path name is included.                          */

OBJECT     = COLUMN
  NAME          = MISSION_PHASE_NAME
  COLUMN_NUMBER = 3
  START_BYTE    = 77
  BYTES         = 30
  DATA_TYPE     = CHARACTER
  DESCRIPTION   = "The mission phase during which the observations
     were obtained."
END_OBJECT = COLUMN

OBJECT     = COLUMN
  NAME          = TARGET_NAME
  COLUMN_NUMBER = 4
  START_BYTE    = 110
  BYTES         = 12
  DATA_TYPE     = CHARACTER
  DESCRIPTION   = "The target observed."
END_OBJECT = COLUMN

OBJECT     = COLUMN
  NAME          = PRODUCT_ID
  COLUMN_NUMBER = 5
  START_BYTE    = 125
  BYTES         = 24
  DATA_TYPE     = CHARACTER
  DESCRIPTION   = "PRODUCT_ID from the PDS label"
END_OBJECT = COLUMN

OBJECT     = COLUMN
  NAME          = PRODUCT_VERSION_ID
```

```
  COLUMN_NUMBER = 6
  START_BYTE    = 152
  BYTES         = 5
  DATA_TYPE     = CHARACTER
  DESCRIPTION   = "PRODUCT_VERSION_ID from the PDS label"
END_OBJECT = COLUMN

OBJECT     = COLUMN
  NAME          = PRODUCT_CREATION_TIME
  COLUMN_NUMBER = 7
  START_BYTE    = 159
  BYTES         = 19
  DATA_TYPE     = TIME
  DESCRIPTION   = "Creation time from the PDS label"
END_OBJECT = COLUMN

OBJECT     = COLUMN
  NAME          = DATA_SET_ID
  COLUMN_NUMBER = 8
  START_BYTE    = 180
  BYTES         = 23
  DATA_TYPE     = CHARACTER
  DESCRIPTION   = "DATA_SET_ID from the PDS label."
END_OBJECT = COLUMN

OBJECT     = COLUMN
  NAME          = STANDARD_DATA_PRODUCT_ID
  COLUMN_NUMBER = 9
  START_BYTE    = 206
  BYTES         = 9
  DATA_TYPE     = CHARACTER
  DESCRIPTION   = "STANDARD_DATA_PRODUCT_ID from the PDS label.
   Identifies the data product in the volume archive."
END_OBJECT = COLUMN

OBJECT     = COLUMN
  NAME          = START_TIME
  COLUMN_NUMBER = 10
  START_BYTE    = 217
  BYTES         = 23
  DATA_TYPE     = TIME
  DESCRIPTION   = "The UTC START_TIME value from the PDS label"
END_OBJECT = COLUMN
```

```
  OBJECT     = COLUMN
    NAME           = STOP_TIME
    COLUMN_NUMBER = 11
    START_BYTE     = 241
    BYTES          = 23
    DATA_TYPE      = TIME
    DESCRIPTION    = "The UTC STOP_TIME value from the PDS label"
  END_OBJECT = COLUMN

  OBJECT     = COLUMN
    NAME           = SPACECRAFT_CLOCK_START_COUNT
    COLUMN_NUMBER = 12
    START_BYTE     = 265
    BYTES          = 13
    DATA_TYPE      = ASCII_INTEGER
    DESCRIPTION    = "The SPACECRAFT_CLOCK_START_COUNT value from the PDS
      label. This is the MET of the beginning of the observation."
  END_OBJECT = COLUMN

  OBJECT     = COLUMN
    NAME           = SPACECRAFT_CLOCK_STOP_COUNT
    COLUMN_NUMBER = 13
    START_BYTE     = 279
    BYTES          = 13
    DATA_TYPE      = ASCII_INTEGER
    DESCRIPTION    = "The SPACECRAFT_CLOCK_STOP_COUNT value from the PDS
      label. This is the MET of the end of the observation."
  END_OBJECT = COLUMN

END_OBJECT = INDEX_TABLE
END
```