Software Interface Specification (SIS) for the Lunar Prospector Spectrometer Planetary Data System Files, Version V001

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This document describes the file formats and data processing used for the submission of Lunar Prospector Gamma-Ray Spectrometer (GRS), Neutron Spectrometer (NS) and Alpha Particle Spectrometer (APS) data to the Planetary Data System (PDS).

1. Gamma-Ray Spectrometer (GRS)

1.1 Introduction

The GRS data contains two primary data files: *GRS_spectra_V001.cdf* and *GRS_ThK_V001.cdf*. These data files contain integrated spectra counting rate data and thorium and potassium counting rate data. The primary data files are written in Common Data Format (CDF) which is described in Section 4. In addition, there is an auxiliary data file which contains information regarding times of solar particle events and high voltage changes. The auxiliary data file is written in ASCII format. All of the data in the primary files are binned into 1790 approximately equal area pixels on the Moon. The size of these pixels is 5° x 5° at the equator and extends to 5° caps at the poles.

1.2 GRS Data Contents: Integrated Spectra

Table 1 lists the contents of the GRS integrated spectra file. A description of each variable is given below.

Variable	Type	Unit	Array size	Description
Record	integer	number	[1790]	Record number having values from 1 to 1790.
Pixel	float	degrees	[1790,4]	Minimum and maximum latitude/longitude values for each of the 1790 pixels.
Nspectra	integer	number per pixel	[1790]	Number of 32-second long spectra collected for each of the 1790 pixels.
Accepted	float	counts per 32-seconds	[1790,512,2]	512-element accepted array and 512-element standard deviation of the accepted array for each of the 1790 pixels.
Rejected	float	counts per 32-seconds	[1790,512,2]	512-element rejected array and 512-element standard deviation of the rejected array for each of the 1790 pixels.
Energy	float	MeV per channel	[512]	512-element array containing the gamma-ray energy values for each of the 512 channels.

Table 1: Contents of the GRS_spectra_V001.cdf file.

Record: The *Record* variable is an integer array having a size of 1790 elements. *Record* lists the record number of the data and has values ranging from 1 to 1790.

Pixel: The *Pixel* variable is a float array of size 1790x4 elements. *Pixel* contains the minimum and maximum latitude/longitude values for each of the 1790 pixels. For each pixel, the order of the values is: minimum latitude (value 0), maximum latitude (value 1), minimum longitude (value 2), maximum longitude (value 3).

Nspectra: The *Nspectra* variable is an integer array of size 1790 elements. *Nspectra* contains the number of GRS spectra collected for each pixel. Each GRS spectra contains data collected over 32-seconds.

Accepted: The *Accepted* variable is a float array of size 1790x512x2 elements. *Accepted* contains two 512-element arrays for each of the 1790 pixels. The first 512-element array is the GRS accepted spectra as measured in counts per 32-seconds. Events which trigger only the bismuth germanate (BGO) crystal of the GRS without triggering the anti-coincidence shield (ACS) are labeled accepted events. The accepted events are considered the true gamma-ray events. The second 512-element array contains the standard deviation of the accepted spectra. More information regarding accepted spectra can be found in Feldman et al. [1, 2].

Rejected: The *Rejected* variable is a float array of size 1790x512x2 elements. *Rejected* contains two 512-element arrays for each of the 1790 pixels. The first 512-element array is the GRS rejected spectra as measured in counts per 32-seconds. Events which trigger both the BGO crystal and ACS are labeled rejected events. The rejected spectra contain events due to energetic charged particles and gamma-rays which scatter in both the BGO and ACS. The second 512-element array contains the standard deviation of the rejected spectra. More information regarding rejected spectra can be found in Feldman et al. [1, 2].

Energy: The *Energy* variable is a float array of size 512 elements. *Energy* contains the gamma-ray energy calibration values which correspond to each of the 512 channels of the accepted and rejected spectra.

1.3 GRS Data Contents: Thorium and Potassium Counting Rates

Table 2 lists the contents of the GRS thorium and potassium counting rate file. A description of each variable is given below.

Record: The *Record* variable is an integer array having a size of 1790 elements. *Record* lists the record number of the data and has values ranging from 1 to 1790.

Pixel: The *Pixel* variable is a float array of size 1790x4 elements. *Pixel* contains the minimum and maximum latitude/longitude values for each of the 1790 pixels. For each pixel, the order of the values is: minimum latitude (value 0), maximum latitude (value 1), minimum longitude (value 2), maximum longitude (value 3).

Variable	Type	Unit	Array size	Description
Record	integer	number	[1790]	Record number having values from 1 to 1790.
Pixel	float	degrees	[1790,4]	Minimum and maximum latitude/longitude values for each of the 1790 pixels.
Nspectra	integer	number per pixel	[1790]	Number of 32-second long spectra collected for each of the 1790 pixels.
Thorium	float	counts per 32-seconds	[1790,2]	Number of thorium counts per 32-seconds and standard deviation for the thorium counts.
Potassium	float	counts per 32-seconds	[1790,2]	Number of potassium counts per 32-seconds and standard deviation for the potassium counts.

Table 2: Contents of the GRS_ThK_V001.cdf file.

Nspectra: The *Nspectra* variable is an integer array of size 1790 elements. *Nspectra* contains the number of GRS spectra collected for each pixel. Each GRS spectra contains data collected over 32-seconds.

Thorium: The *Thorium* variable is a float array of size 1790x2 elements. *Thorium* contains both the thorium counting rate and the standard deviation of the thorium counting rate for each pixel. The thorium counting rate is calculated by summing counts from the accepted spectra within an energy band (2.4 to 2.8 MeV) around the thorium gamma-ray line of 2.6 MeV.

Potassium: The *Potassium* variable is a float array of size 1790x2 elements. *Potassium* contains both the potassium counting rate and the standard deviation of the potassium counting rate for each pixel. The potassium counting rate is calculated by summing counts from the accepted spectra within an energy band (1.3 to 1.5 MeV) around the potassium gamma-ray line of 1.46 MeV.

1.4 GRS Data Processing: Integrated Spectra

The following processing steps have been done to create the GRS integrated spectra.

Deadtime: Instrument corrections have been made for the GRS deadtime that has been electronically measured. The deadtime correction used is $Data_{new} = Data_{old}/(1\text{-}Deadtime)$.

Gain Corrections: Instrument corrections have been made for the gain drift in the GRS. The gain corrections were made by calculating the GRS gain over 12-hour intervals starting from 16 Jan. 1998, at 0 hours, 0 minutes. This time was chosen because it was the first full day that LP was in its final mapping orbit. Gamma-ray lines of energies 0.478 MeV (taken from GRS category 3/4 data; see the Instrument Description Document [2] for a description of GRS Category 3/4 data), 2.21 MeV, 4.43 MeV, and 6.13 MeV were used to make the 12-hour gain corrections. Using these four energies, gain and offset values were calculated for each 12-hour interval. These gain parameters are then used to correct the data back to the gain level that was present during the 12 hour interval starting from 16 Jan. 1998, 0 hours, 0 minutes. In addition, there have been times when the GRS high voltage was changed resulting in gain shifts that occur in the middle of the twelve hour intervals. The times of these discrete gain changes have been tabulated and accounted for in the gain correction process.

Solar Energetic Particle (SEP) Events: SEP effects have been accounted for by de-selecting data that was taken during periods of intense solar activity. During these periods, the GRS detector was saturated and/or had unacceptably high background, so regular data collection was not possible. The times of these SEP events are listed in the auxiliary data file.

Galactic Cosmic Ray (GCR) Effects: GCR variations have been taken into account by correcting the data for the variation in cosmic ray flux that initiates the gamma-rays coming from the Moon. This correction is carried out by using the gamma-rays from 6.13 MeV as a monitor of the baseline cosmic ray flux. The 6.13 MeV gamma-rays come from oxygen which has very little compositional variation over the lunar surface, so these gamma-rays should serve as a good baseline cosmic ray flux monitor. The flux of 6.13 MeV gamma-rays is smoothed over two hours and normalized. Both the accepted and rejected spectra are divided by this normalized flux to correct for the GCR variations. It should be noted that this is a preliminary correction which is subject to change in later revisions of the data.

Binning of Data: Each spectrum has been binned into the approximately equal-area pixels by using the spacecraft latitude/longitude position at the time the spectrum was taken. It is assumed that all counts are uniformly emitted from the pixel directly underneath the spacecraft at the time of measurement.

Standard Deviation: The 512-element accepted and rejected standard deviation arrays are the calculated standard deviations for each channel.

1.5 GRS Data Processing: Thorium and Potassium Counts

The following processing steps have been done to create the GRS thorium and potassium counting rate data.

Data Selection: The data for the thorium and potassium counts were taken by summing counts from the accepted spectra around the central energy peaks for each gamma-ray line. Corrections for deadtime, gain, solar energetic particles events, and galactic cosmic rays were applied to the spectra before summing the counts. For the thorium line, the counts were summed within an energy band of 2.4 to 2.8 MeV; for the potassium line, the counts were summed within an energy band of 1.3 to 1.5 MeV. No corrections for gamma-ray background have been made.

Latitude Correction: A correction was made to the data to account for a non-symmetric response of the GRS to gamma-rays as a function of incident angle and energy. This correction is characterized by a 4th degree polynomial in sin(latitude):

$$f(x) = 1 + a_1 \sin(\lambda) + a_2 \sin^2(\lambda) + a_3 \sin^3(\lambda) + a_4 \sin^4(\lambda)$$

where the a_i coefficients are different for the thorium and potassium corrections.

Binning of Data: Each of the counting rates has been binned into the approximately equal-area pixels by using the spacecraft latitude/longitude position at the time the data was taken. It is assumed that all counts are uniformly emitted from the pixel directly underneath the spacecraft at the time of measurement.

Standard Deviation: The thorium and potassium standard deviation values are the calculated standard deviations for each summed counting rate.

1.6 GRS Auxiliary Data File

In addition to the counting rate data, the GRS data set contains an auxiliary file in ASCII format: *Auxiliary_V001.txt*. The auxiliary file contains two items for the GRS: times of solar energetic particle events which have been omitted from the data; times of high voltage changes for the GRS detector.

2. Neutron Spectrometer (NS)

2.1 Introduction

The NS data contains one primary data file: *NS_V001.cdf*. The NS data file contains counting rate data for thermal and epithermal neutrons and is written in CDF. In addition, the file *Auxiliary_V001.txt*, contains information regarding times of solar particle events. The auxiliary data file is written in ASCII format. The data in the primary file are binned into 1790 approximately equal area pixels on the Moon. The size of these pixels is 5° x 5° at the equator and extends to 5° caps at the poles.

2.2 NS Data Contents

Table 3 lists the contents of the NS counting rate file. A description of each variable is given below.

Variable	Type	Unit	Array size	Description
Record	integer	number	[1790]	Record number having values from 1 to 1790.
Pixel	float	degrees	[1790,4]	Minimum and maximum latitude/longitude values for each of the 1790 pixels.
Nspectra	integer	number per pixel	[1790]	Number of 32-second long spectra collected for each of the 1790 pixels.
Thermals	float	counts per 32-seconds	[1790,2]	Number of thermal neutron counts per 32-seconds and the standard deviation for the thermal neutron counts.
Epithermals	float	counts per 32-seconds	[1790,2]	Number of epithermal neutron counts per 32-seconds and the standard deviation for the epithermal neutron counts.

Table 3: Contents of the NS_V001.cdf file.

Record: The *Record* variable is an integer array having a size of 1790 elements. *Record* lists the record number of the data and has values ranging from 1 to 1790.

Pixel: The *Pixel* variable is a float array of size 1790x4 elements. *Pixel* contains the minimum and maximum latitude/longitude values for each of the 1790 pixels. For each pixel, the order of the values is: minimum latitude (value 0), maximum latitude (value 1), minimum longitude (value 2), maximum longitude (value 3).

Nspectra: The *Nspectra* variable is an integer array of size 1790 elements. *Nspectra* contains the number of NS spectra collected for each pixel. Each NS spectra contains data collected over 32-seconds.

Thermals: The *Thermals* variable is a float array of size 1790x2 elements. *Thermals* contains both the thermal neutron counting rate and the standard deviation of the thermal counting rate for each pixel. The thermal neutron counting rate is the difference in the counting rate between the HeCd and HeSn detectors.

Epithermals: The *Epithermals* variable is a float array of size 1790x2 elements. *Epithermals* contains both the epithermal counting rate and the standard deviation of the epithermal counting rate for each pixel. The epithermal counting rate is the counting rate of the HeCd detector.

2.3 NS Data Processing

The following steps have been done to create the NS neutron counting rate data.

Spacecraft Processing: The thermal and epithermal counts are calculated on board the Lunar Prospector spacecraft using the integrated spectra. While the integrated spectra telemetered to the ground are 5-bit spectra having channel values from 0 to 31 (see Feldman [1, 2] for a description of the NS integrated spectra), the data for the maps are calculated on board the spacecraft using 8-bit spectra (having values from 0 to 254). For the thermal maps, the summed counting rates from both the HeCd and HeSn detectors are calculated from the 8-bit on-board spectra by summing the counts between channels 120 and 247. The thermal map is then the difference in counts between these two counting rates. For the epithermal maps, the summed counting rate between channels 120 and 247 from the HeCd detector is computed.

SEP Events: SEP effects have been accounted for by de-selecting data that was taken during periods of intense solar activity. During these periods, the NS detector was saturated and/or had unacceptably high background, so regular data collection was not possible. The times of these SEP events are listed in the auxiliary data file.

Galactic Cosmic Ray (GCR) Effects: GCR variations have been taken into account by correcting the data for the variation in cosmic ray flux that initiates the gamma-rays coming from the Moon. This correction is carried out by using the gamma-rays from 6.13 MeV as a monitor of the baseline cosmic ray flux. The 6.13 MeV gamma-rays come from oxygen which has very little compositional variation over the lunar surface, so these gamma-rays should serve as a good baseline cosmic ray flux monitor. The flux of 6.13 MeV gamma-rays is smoothed over two hours and normalized. Both the thermal and epithermal counting rates are divided by this normalized flux to correct for the GCR variations. It should be noted that this is a preliminary correction which is subject to change in later revisions of the data.

Latitude Correction: A correction was made to the data to account for a non-symmetric response of the NS to neutrons as a function of incident angle. This correction is characterized by a 4th degree polynomial in cos(latitude):

$$f(x) = 1 + a_1 \cos^2(\lambda) + a_2 \cos^4(\lambda).$$

Binning of Data: Each neutron counting rate has been binned into the approximately equal-area pixels by using the spacecraft latitude/longitude position at the time the counts were measured. It is assumed that all counts are uniformly emitted from the pixel directly underneath the spacecraft at the time of measurement.

Standard Deviation: The thermal and epithermal neutron standard deviation values are the calculated standard deviations for each summed counting rate.

2.4 NS Auxiliary Data File

In addition to the counting rate data, the NS data set contains an auxiliary file in ASCII format: *Auxiliary_V001.txt*. The auxiliary file contains the times that data have been omitted from the NS data set due to solar energetic particle events.

3. Alpha Particle Spectrometer (APS)

Since one purpose of the APS is to look for time variable lunar gas release events, the APS data will be sorted by time instead of averaging into lunar latitude/longitude pixels. The number of records is therefore not fixed, but is determined by the number of measured APS events (note: the term APS events does not refer to gas release events, but rather to each measured alpha particle). Table 4 lists the contents of the APS data. A description of each variable is given below.

Variable	Type	Unit	Description
Face	integer	<none>	APS face number having values from 1 to 5
Latitude	float	degrees	Spacecraft latitude for nearest 32-seconds.
Longitude	float	degrees	Spacecraft longitude for nearest 32-seconds.
Height	float	kilometers	Spacecraft height for nearest 32-seconds.
ERT	float	seconds since Jan 1, 1970	Earth receive time for each APS event.
PHV	integer	channel	Pulse height value for each APS event.
Long_look_angle	float	degrees	Look angle from the orbital plane for each event.
APS_scalar	integer	counts per 32-seconds	APS counting rate for the nearest 32-seconds.

Table 4: Contents of the APS.cdf file.

Face: The *Face* variable is an integer variable. *Face* give the face number that was triggered in each APS event. Figure 1 shows a diagram of how each APS face is orientated relative to the LP spacecraft.

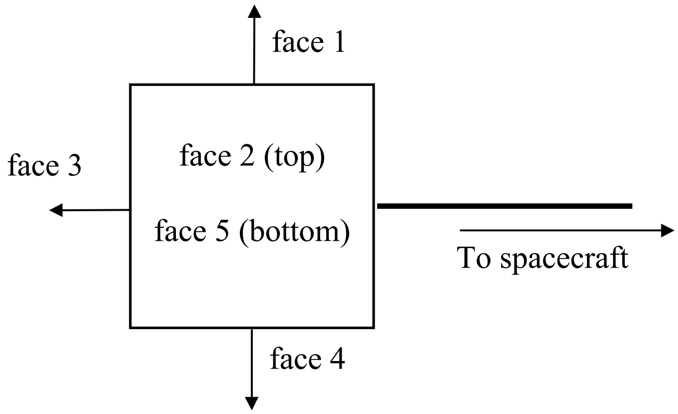

Figure 1: APS Detector view from top spin axis of the Lunar Prospector spacecraft.

Latitude: Spacecraft longitude to the nearest 32-seconds.

Longitude: Spacecraft height to the nearest 32-seconds.

Height: Spacecraft height to the nearest 32-seconds.

ERT: Earth receive time for to the nearest 0.5 second for each of the APS events. *ERT* is measured in seconds since January 1, 1970.

PHV: Pulse height value of each APS event. The PHV is measured as a channel number having values from 0 to 127.

Long_look_angle: The *Long_look_angle* variable gives the longitudinal angle of each face for each APS event. This angle is defined as the angle between normal to the detector and the orbital plane.

APS_scalar: The *APS_scalar* variable gives the total number of APS events in the nearest 32-second data frame.

The APS data set is still under construction so it is not being included in this PDS submission. When the APS data set is submitted, more details will be given about the specific formatting of the data.

4. Common Data Format

Common Data Format (CDF) is being used to store the majority of the spectrometer data. CDF is a self-describing binary data format such that all data files contain both the data and information with which to read the data. Access to the data is enabled using routines written in various computer languages such as C, Fortran, and IDL. CDF data files and software is supported for the following computer platforms:

- DEC Alpha/OSF1 & OpenVMS
- DECstation/ULTRIX & VMS
- HP 9000 series/HP-UX
- PC MS-DOS/Windows 3.x, Windows 95/NT, Linux & QNX
- IBM RS600 series/AIX
- Macintosh
- NeXT/Mach
- SGI Iris, Power series and Indigo/IRIX
- Sun/SunOS & SOLARIS
- VAX/VMS

CDF was created by the National Space Science Data Center (NSSDC) at Goddard Spaceflight Center. Extensive documentation describing CDF can be found on the web page http://nssdc.gsfc.nasa.gov/cdf/cdf_home.html.

To help describe and use the CDF files, this PDS release contains informational files which describe the contents of each CDF file. These files (which have an extension name of *-info.txt*) list the variables, variable names, and variable attributes included in the CDF files. A program written in Interactive Data Language (IDL) (*load_cdf.pro*) has been included which extracts variables from CDF files when the variable names are known.

5. Summary of Data Files

The following files make up the GRS and NS PDS Version V001 data submission:

Data files:

1.	Neutron data	NS_V001.cdf
2.	Gamma-ray spectrum	GRS_spectra_V001.cdf
3.	Thorium and potassium data	GRS_ThK_V001.cdf
4.	Auxiliary data	Auxiliary_V001.txt

Content of data files:

5.	Neutron data	NS_V001-info.txt
6.	Gamma-ray spectrum	GRS_spectra_V001-info.txt
7.	Thorium and potassium data	GRS_ThK_V001-info.txt

Programs:

8.	Read CDF files	load_cdf.pro

6. References

References [1] and [2] describe in detail the instrumentation used to produce this data set. Descriptions of the data sets themselves and preliminary scientific conclusions drawn from the data can be found in references [3, 4, 5, 6].

[1] W. C. Feldman, B. L. Barraclough, K. R. Fuller, D. J. Lawrence, S. Maurice, M. C. Miller, T. H. Prettyman, and A. B. Binder, The Lunar Prospector Gamma-Ray and Neutron Spectrometers, *Nuclear Instruments and Methods in Physics Research*, in press, 1998.

[2] W. C. Feldman, D. J. Lawrence, S. Maurice, B. L. Barraclough, K. R. Fuller, R. Belian, Lunar Prospector Spectrometers Instrument Description Document, Los Alamos National Laboratory Internal Report, LAUR-99-2752, 1999.

[3] D. J. Lawrence, W. C. Feldman, B. L. Barraclough, A. B. Binder, R. C. Elphic, S. Maurice, and D. R. Thomsen, Global Elemental Maps of the Moon: The Lunar Prospector Gamma-Ray Spectrometer, *Science*, **281**, 1484-1489, 1998.

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[5] W. C. Feldman, S. Maurice, A. B. Binder, B. L. Barraclough, R. C. Elphic, and D. J. Lawrence, Fluxes of Fast and Epithermal Neutrons from Lunar Prospector: Evidence for Water Ice at the Lunar Poles, *Science*, **281**, 1496-1500, 1998.

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