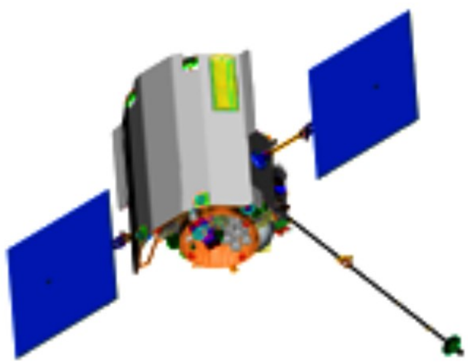
MESSENGER Advanced Product Specification

VIRS Spectral Cube of Mercury (MEAP-1)
UVVS Spectral Cube of Mercury (MEAP-2)
Mercury Energetic Event Table (MEAP-3)
Mercury Thermal Neutron Map (MEAP-4)
Enhanced Gamma-Ray Spectrometer Data Set (MEAP-5)

Version 2.0
February 10, 2017



MEAP

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Document Review

This document and the archive it describes will be submitted to PDS review September 28, 2016 for acceptance into the PDS archive.

Noam Izenberg, MEAP project lead and MASCS instrument scientist and VIRS and UVVS Cube creator, David Lawrence, NS instrument scientist and EE Table creator, Patrick Peplowski, GRS Instrument scientist and Thermal Neutron Map creator have reviewed and approved this document.

Susan Slavney, PDS Node Representative, has reviewed and approved this document.

Document Change History

Revision Number	Revision Date	Author	Section	Remarks
1.0	9/28/16	N. Izenberg, D. Lawrence, P. Peplowski, J. Ward	All	Initial version.
2.0	2/10/17	N. Izenberg, D. Lawrence, P. Peplowski, J. Ward	5.1.3, 5.2.3, 5.4.3.3, 5.4.3.4, 9.4	Revisions resulting from MEAP-1, -3, and -4 peer review.

TBD Log

	Description
1.	MEAP-2 and -5 are expected to be completed and released in FY 2017. The applicable sections of this document will be completed by that time.

Table of Contents

1 Purpose and Scope of Document

1.1 *Purpose*

The purpose of this document is to provide users of the MESSENGER advanced products (MEAPs) with a detailed description of each product. There are five MEAPs in all:

MEAP-1: **VIRS Spectral Cube of Mercury DAP (VIRS Cube)**
MEAP-2: **UVVS Spectral Cube of Mercury DAP (UVVS Cube)**
MEAP-3: **Mercury Energetic Electron Event Tables DDR (EETs)**
MEAP-4: **Mercury Thermal Neutron Map DAP (TN Map)**
MEAP-5: **Enhanced Gamma Ray Spectrometry Data Set RDR (GRS Enhanced)**

The Visible and Infrared Spectrograph (VIRS) Cube, Ultraviolet to Visible Spectrometer (UVVS) Cube, and Gamma Ray Spectrometer (GRS) TN Map are all Derived Analysis Products (DAP). The Neutron Spectrometer (NS) EETs are Derived Data Records (DDRs). The GRS Enhanced Data set is a Reduced Data Record (RDR). MEAP data products are deliverables to the Planetary Data System (PDS) and the scientific community that it supports. All data formats are compliant with PDS4 standards. In addition, this Specification documents the format and content of the MEAP PDS4 archive bundle, the structure in which the data products, documentation, and supporting material are stored. This document is both a data product specification and an archive bundle specification.

The VIRS and UVVS are components of the Mercury Atmosphere and Surface Composition Spectrometer (MASCS). However, they are two separate instruments, each with its own optics, data acquisition, and format, and independent documentation. The VIRS Cube (MEAP-1) refers to the VIRS component of MASCS. The UVVS Cube (MEAP-2) refers to the UVVS component of MASCS.

The GRS and NS instruments are generally referred to as the GRNS instrument. However, they are two separate sensors, each with its own electronics, data acquisition, and format, and independent documentation. MEAP-3 refers to the NS instrument, and MEAP-4 and -5 refer to the GRS instrument.

1.1 *Scope*

The goal of this document is to provide thorough and complete information, so that PDS users can read and understand the data products long after the completion of the MESSENGER mission. As such, this document provides a common reference for scientists, data analysts, software engineers and researchers to access and understand the MEAP archived data.

2 Applicable Documents

This Specification references the following documents:

1. Planetary Data System Standards Reference, Version 1.7.0, Sept. 15, 2016.
2. Planetary Science Data Dictionary Document, Version 1.7.0.0, Sept. 28, 2016.
3. Planetary Data System (PDS) PDS4 Information Model Specification, Version 1.7.0.0, Sept. 28, 2016.
4. Data Providers' Handbook: Archiving Guide to the PDS4 Data Standards, Version 1.4.1, Feb. 23, 2016.
5. MESSENGER Mercury: Surface, Space Environment, Geochemistry, Ranging; A mission to Orbit and Explore the Planet Mercury, Concept Study, March 1999. Document ID number FG632/99-0479.
6. GRS Flight Software Specification, Draft Dec 15, 2003.
7. MESSENGER Experiment Data Record (EDR) Software Interface Specification for the Gamma Ray Spectrometer.
8. MESSENGER Data Management and Science Analysis Plan. The Johns Hopkins University, APL.
9. MESSENGER Project Archive Generation, Validation, and Distribution Plan.
10. MESSENGER Mercury: Surface, Space Environment, Geochemistry, Ranging; A mission to Orbit and Explore the Planet Mercury, Concept Study, March 1999.
11. [PLR] Appendix 7 to the Discovery Program Plan; Program Level Requirement for the MESSENGER Discovery project, June 20, 2001.
12. The MESSENGER Gamma-Ray and Neutron Spectrometer, Space Science Reviews 131, 339-391, 2007.
13. MESSENGER Gamma Ray Spectrometer Calibrated Data Record, Reduced Data Record, and Derived Analysis Product Software Interface Specification.
14. Peplowski, P. N. et al., Geochemical terranes of Mercury's northern hemisphere as revealed by MESSENGER neutron measurements, Icarus 253, 346–363, 2015.
15. MESSENGER X-Ray Spectrometer Calibrated and Reduced Data Record Software Interface Specification.
16. MESSENGER Mercury: Surface, Space Environment, Geochemistry, Ranging; A mission to Orbit and Explore the Planet Mercury, Concept Study, March 1999. Document ID number FG632/99-0479.
17. MESSENGER MASCS VIRS Calibrated Data Record, Derived Data Record, and Derived Analysis Product Software Interface Specification.
18. MESSENGER Advanced Products: UV-NIR Hyperspectral Cubes, Energetic Electron Events, Thermal Neutron Maps, and Enhanced Gamma Ray Data Set, NASA PDART grant proposal NNX15AJ46G.
19. MESSENGER Neutron Spectrometer Calibrated and Derived Data Record Software Interface Specification.
20. Lawrence, David J., Brian J. Anderson, Daniel N. Baker, William C. Feldman, George C. Ho, Haje Korth, Ralph L. McNutt et al. "Comprehensive survey of energetic electron events in Mercury's magnetosphere with data from the MESSENGER Gamma-Ray and Neutron Spectrometer." Journal of Geophysical Research: Space Physics 120, no. 4 (2015): 2851-2876, doi:10.1002/2014JA020792.

21. MESSENGER MASCS UVVS Calibrated Data Record, Derived Data Record, and Derived Analysis Product Software Interface Specification.
22. MESSENGER MDIS CDR/RDR Software Interface Specification.

3 Relationships with other Interfaces

The VIRS Cube DAP data products are dependent on the VIRS Derived Data Record (DDR) data products. Changes to the DDR product, or the CDR product that produces the DDR product will require revisions to the associated DAP product. The VIRS Cube data products are also dependent on valid SPICE Kernel generation for timing and spatial information. Changes or revisions to the SPICE Kernel will result in revisions to the VIRS Cube DAP products. Changes to data processing programs that derive the DAP from DDR may also result in revised data products.

The UVVS Cube DAP data products are dependent on the UVVS Derived Data Record (DDR) data products. Changes to the DDR product, or the CDR product that produces the DDR product will require revisions to the associated DAP product. The UVVS Cube data products are also dependent on valid SPICE Kernel generation for timing and spatial information. Changes or revisions to the SPICE Kernel will result in revisions to the UVVS Cube DAP products. Changes to data processing programs that derive the DAP from DDR may also result in revised data products.

The NS EET DDR data product is dependent on the NS Calibrated Data Record (CDR) data products. Changes to the CDR product will require revisions to the associated DAP product. The NS EET DDR product is also dependent on valid SPICE Kernel generation for timing and spatial information. Changes or revisions to the SPICE Kernel will result in revisions to the NS EET DDR. Changes to data processing programs that derive the DDR from CDR may also result in revised data product.

The GRS TN Map DAP data products are dependent on the GRS Calibrated Data Record (CDR) data products. Changes to the CDR product will require revisions to the associated DAP product. The GRS DAP data products are also dependent on valid SPICE Kernel generation for timing and spatial information. Changes or revisions to the SPICE Kernel will result in revisions to the GRS DAP products. Changes to data processing programs that derive the DAP from CDR may also result in revised CDR data products.

The GRS Enhanced RDR data product is dependent on the GRS Calibrated Data Record (CDR) data products. Changes to the CDR product will require revisions to the associated RDR product. The GRS Enhanced RDR product is also dependent on valid SPICE Kernel generation for timing and spatial information. Changes or revisions to the SPICE Kernel will result in revisions to the GRS Enhanced RDR. Changes to data processing programs that derive the RDR from CDR may also result in revised data products.

4 Roles and Responsibilities

The MEAP project PI (Noam Izenberg) is ultimately responsible for delivery and support of all MESSENGER Advanced Products. David J. Lawrence is the cognizant MEAP project Co-I and responsible for generation and validation of MEAP-3. Patrick Peplowski is the cognizant MEAP project Co-I and responsible for generation and validation of MEAP-4 and -5. Applied Coherent Technology Corporation (ACT) provides some archiving support, and the PDS has review and interface roles outlined in the MESSENGER Advanced Products: UV-NIR Hyperspectral Cubes, Energetic Electron Events, Thermal Neutron Maps, and Enhanced Gamma Ray Data Set proposal (NNH14ZDA001N-PDART).

5 Data Product Characteristics and Environment

5.1 *Overview*

The data for all MEAPs were acquired during 3 years of primary-plus-extended missions of MESSENGER from 18 March 2011 to 17 March 2014. During that time, MASCS obtained over 5 million VIRS reflectance spectra and 3200 UVVS spectra, the NS recorded over 2700 EE events, and the GRS recorded over 2 million gamma-ray and neutron spectra. Standard data products for all instruments were delivered to the scientific community in calibrated form via the PDS by the MESSENGER mission.

5.1.1 VIRS Cube DAP

MASCS VIRS provided spectral observations from 300 nm to 1450 nm at a 5 nm spectral resolution. During the primary and extended missions in orbit around Mercury, VIRS acquired over 5 million spectra of Mercury's surface. VIRS orbital observations had varying spatial resolutions, as spacecraft altitude and ground speed changes the size and smear of the 0.023° circular field of view.

During the primary and extended missions, VIRS accumulated over 8000 ground tracks across the planet to create a global spectral dataset. Spacecraft pointing constraints limit VIRS' viewing geometry to a phase angle (α) of 78°-102° and average incidence (i) and emission (e) angles of 45° each. A large number of observations are only possible at relatively high incidence or emission angles. In addition, the progression of MESSENGER's orbit around Mercury results in an extremely variable thermal environment, which affects background signal levels and thus the data quality in near infrared wavelengths.

Calibration of MASCS data was part of the standard pipeline for data disseminated to the public. Calibrated radiance, and derived surface reflectance VIRS data was a standard released product of the MESSENGER mission. The processes of radiance calibration, reflectance conversion, and photometric are detailed in the VIRS SIS (Document 17).

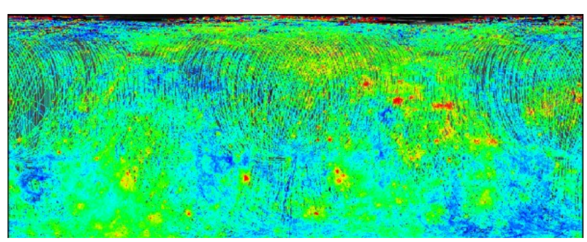

Figure 1. *Global 750-nm reflectance map from VIRS data photometrically corrected to i=45°, e= 45°, α=90°.*

While individual spectra can be valuable, the global perspective is essential to understand spatial relationships and correlation with geology. Fig. 1 shows an integrated global map at 750 nm observations of Mercury from VIRS to date. It is a delivered PDS DAP (the only map product delivered by VIRS), but also a de-facto prototype layer of the 105 layer global spectral cube. The map is color-coded reflectance with hotter colors representing brighter surface features (up to reflectance values of ~0.13).

5.1.2 UVVS Cube DAP

MASCS UVVS was a scanning grating spectrometer that, in surface observation configuration, provides spectral observations from 210 nm to 300 nm across 660 grating steps. The 0.05° x 0.04° entrance aperture for UVVS is both slightly offset from and significantly larger than VIRS. In order to obtain a surface measurement, the instrument footprint had to be held stationary on a target point for approximately 35 seconds while the grating scans. This required a dedicated targeting and tracking spacecraft operation, which is why UVVS data was only taken at discrete grid points and specific targets. MESSENGER's highly elliptical orbit restricted this campaign mostly to the southern hemisphere UVVS calibration (see Document 21).

Fig. 2 shows a map view displaying individual UVVS footprint locations, color coded with a ratio of 215 nm to 290 nm reflectance where lower (bluer) values may indicate potentially lower iron content.

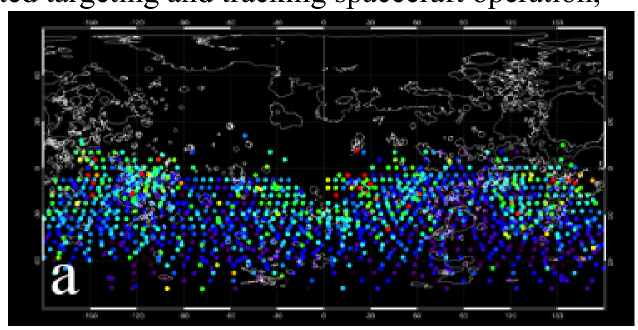

Figure 2. *Southern hemisphere point map of UVVS-measured reflectance ratio 215 nm / 290 nm.. Blue-Red for low-high ratio values.*

5.1.3 EET DDR

The Neutron Spectrometer (NS) was one of the instruments onboard the MESSENGER spacecraft. It was designed to observe the neutrons emitted from Mercury's surface in the thermal, epithermal, and fast energy ranges, from ~ 0.01 eV to 7 MeV, that are produced by nuclear reactions by the cosmic ray background (CRB). The NS was designed to separately measure thermal and epithermal neutrons using the Doppler filter technique.

The NS indirectly detected energetic electron (EE) events via bremsstrahlung photons that were emitted when instrument and spacecraft materials stopped electrons with energies of tens to hundreds of keV (Lawrence et al., 2015). NS data taken after 18 March 2011 identified over 4000 EE events. The duration of EE events ranged from tens of seconds to almost 20 minutes. EE events were classified as bursty or smooth, such that bursty events showed large count rate variability within an event, and smooth events showed small count rate variability. Almost all EE events were detected within Mercury's magnetosphere on closed field lines. The occurrences of EE events are stochastic in nature, but are located in well-defined regions with clear boundaries that persist in time, and form "quasi-permanent structures". Bursty events occur closer to dawn and at higher latitudes compared to smooth events, which are seen near noon-todusk local times at lower latitudes. A subset of EE events showed strong periodicities that ranged from hundreds of seconds to tens of milliseconds.

The NS had an order-of-magnitude larger sensitivity for EE events than the MESSENGER Energetic Particle Spectrometer (EPS). At the time that the MESSENGER data archive was being planned, it was not anticipated that the NS would provide such a robust measure of EE events. Now that its capability has been demonstrated, these data provide a valuable resource for many kinds of studies of Mercury's magnetosphere.

5.1.4 TN Map DAP

MESSENGER Gamma-Ray Spectrometer (GRS) Anti-Coincidence Shield (ACS) data have been used to map variations in thermal neutron (TN) absorbing elements across Mercury's surface. This information has been used to map major geochemical units across the same region.

The MESSENGER Gamma-Ray Spectrometer (GRS) consisted of a high-purity Ge (HPGe) sensor surrounded by a BC454 anti-coincidence shield (ACS) for background reduction. The HPGe offered exceptional energy resolution, which was necessary to characterize many elements of interest on Mercury (e.g. Na, Cl). HPGe had to be operated at cryogenic temperatures, and as a result the GRS included a cryocooler to keep the sensor at <90 K. The ACS measured incident neutrons and charged particles, the latter providing a veto signal to reduce backgrounds in the HPGe resulting from galactic cosmic rays.

The GRS operated at peak performance from shortly after MESSENGER's orbit insertion about Mercury (18 March 2011) until 11 October 2011. Data acquired after 11 October 2011 was subject to periodic degradation in HPGe energy resolution due to anomalous low-energy counts. The HPGe detector was operated intermittently in 2012 until the failure of the cryocooler on 15 June. The failure occurred after ~9,500 hours of operation, well past the estimated cooler lifetime of 8,000. The ACS was operated near continuously, and on 25 February 2013, a flight software upgrade was uploaded to optimize ACS neutron measurements. ACS neutron measurements are complementary to those of the MESSENGER Neutron Spectrometer.

The Thermal Neutron map is derived from data collected from 1 March 2013 to 28 Feb 2014; one year of data collection that began shortly after the GRS shield was reprogrammed for the enhanced neutron measurements.

Analysis of ACS datasets have led to the first map of variable abundances of thermal neutron absorbing elements on Mercury's surface. Because this product was not anticipated during the formulation of the MESSENGER mission, it was not incorporated into MESSENGER PDS deliveries.

5.1.5 GRS Enhanced

TBD.

5.2 *Data Product Overview*

5.2.1 VIRS Cube DAP Overview

The VIRS Spectral Cube is spatially mosaicked into 54 non-overlapping, 64 pixel/degree tiles similar to the Mercury Dual Imaging System's (MDIS) 8-color imaging RDR of Mercury (Applicable Document 22). Each tile corresponds to the NW, NE, SW, or SE quadrant of one of the pre-existing Mercury non-polar charts, or one of the two polar charts.

Map tiles are named based on the quadrant of the Mercury chart they span:

VIRS_CUBE_64PPD_Hxxdd.IMG

where:

Hxx = Mercury chart designation
dd = Quadrant within Mercury chart (NW, NE, SW, or SE), or a polar chart (NP, SP)

The following is an example file name with a description of the individual components:

VIRS_CUBE_64PPD_H06NW.IMG

For this image:
Resolution = 64 pixels/degree (64PPD)
Mercury chart = Kuiper (H06)
Quadrant = Northwest (NW)

Each VIRS Cube tile contains the full VIRS Cube for a non-overlapping geographic section of the Mercury globe. Each VIRS Cube tile is accompanied by an ENVI (Exelis Visual Information Solutions, Inc.) header file of the same name with the extension ".HDR", allowing the user to load the PDS image file into the ENVI software application, and a PDS4 label with the extension ".XML".

The VIRS Wavelength table (VIRS_WAVELENGTHS.TAB) is an ASCII table with two columns and 105 records. The columns indicate channel number and center wavelength, and correspond to the wavelength layers of each VIRS cube tile.

5.2.2 UVVS Cube DAP Overview

TBD.

5.2.3 EET Overview

The archive of NS energetic event detections is organized into three event-based tables. The tables include event characteristics, timings, intensities, and other information derived from the NS calibrated data.

The DDR data files are named “ELE_EVT_12HR_ORBIT_2011-2012.TAB”, “ELE_EVT_8HR_ORBIT_2012-2013.TAB”, and “ELE_EVT_8HR_ORBIT_2014-2015.TAB” and are accompanied by labels named “ELE_EVT_12HR_ORBIT_2011-2012.XML”, “ELE_EVT_8HR_ORBIT_2012-2013.XML”, and “ELE_EVT_8HR_ORBIT_2014-2015.XML”.

See the following paper for further details on DDR table generation:

> Lawrence, David J., Brian J. Anderson, Daniel N. Baker, William C. Feldman, George C. Ho, Haje Korth, Ralph L. McNutt et al. "Comprehensive survey of energetic electron events in Mercury's magnetosphere with data from the MESSENGER Gamma-Ray and Neutron Spectrometer." Journal of Geophysical Research: Space Physics 120, no. 4 (2015): 2851-2876, doi: 10.1002/2014JA020792.

Processing steps include:

Fundamental Borated Plastic (BP) versus fast neutron analysis that picks out time periods where the BP low-energy spectral counts rise 5-sigma above the background baseline (see Lawrence et al., 2015). Here low-energy spectral counts are those that are in the lowest 12 channels (channels 0 to 11) of each 64-channel BP 20-s spectral accumulation (see Section 3.1 of Lawrence et al., 2015). The indices for these times are flagged. These flags guide the final processing to get data subsets of each EE event. This processing includes the following:

- Picking out the time series portion of the event when it rises and falls below the 5-sigma threshold for at least five consecutive accumulation times. The maximum time limit for the events is 60 20-sec time increments. The boundaries of the event are when the signal-to-noise falls below 3 at the beginning and end.
- Picking out single accumulation-time events that rise above 9-sigma.

A detailed description of the algorithm used to pick out the EE events is given in Section 4 of Lawrence et al. (2015).

Tables are divided into times of coverage with the following increments:

- 12-hr orbit, 2011-2012: This is data from the 12-hour orbit, taken during 2011 and 2012.
- 8-hr orbit, 2012-2013: This is data taken from the 8-hour orbit, taken during 2012 and 2013. The data from 2011 to 2013 encompasses the entire dataset reported in Lawrence et al. (2015) and contains 2711 events.

8-hr orbit, 2014-2015: This is data taken from the 8-hour orbit in the years 2014 and 2015. This contains an additional 1400 events. The total number of detected EE events for the mission is therefore 2711 + 1400 = 4111.

5.2.4 TN Map Overview

ACS measurements of Mercury originating neutrons have been used to map variations in the abundances of thermal-neutron-absorbing elements across Mercury's surface. The GRS thermal neutron map (MEAP-4), shown in Fig. 3, illustrates variations in the macroscopic neutron absorption cross section (Σ_a) across the northern hemisphere. Σ_a is a bulk parameter that describes the total neutron absorption capacity of the regolith to depths of 10s of cm. Major neutron absorbing elements on Mercury include Cl, Na, and Fe. The creation of the ACS-derived Σ_a map uses the identical map product format used for the GRS K and XRS Mg/Si, Ca/Si, Fe/Si, and S/Si PDS maps (See Applicable Documents 13 and 15).

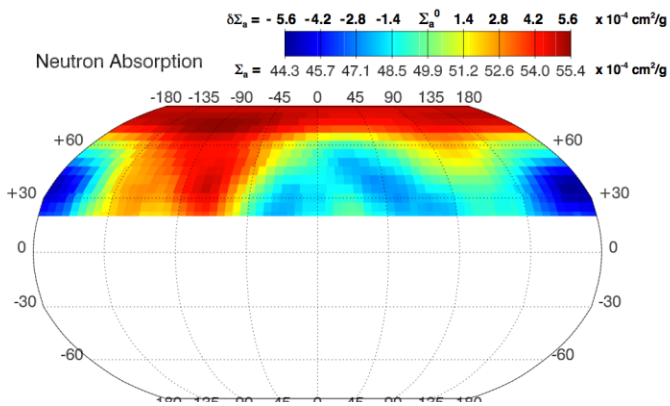

Figure 3. *Thermal neutron absorption (Σ_a) mapped across Mercury's northern hemisphere. Σ_a is a bulk parameter that describes the total neutron absorption capacity of the regolith to depths of 10s of cm. The top scale bar values report variability in absorption ($\delta\Sigma_a$), and the bottom scale bar values report a best estimate of the absolute values.*

The thermal neutron map data file ("THERMAL_NEUTRON_MAP.IMG") contains all relevant data for the map. The map is also provided in jpeg2000 format, along with a PDS label file ("THERMAL_NEUTRON_MAP.XML").

Production of the thermal neutron absorption map was as follows: 1. Raw ACS energy deposition spectra were fit and the neutron capture peak area was extracted, 2. Peak areas were temperature corrected, 3. Peak areas were normalized to a reference altitude (1000 km) altitude and vertical Doppler velocity (0) via comparison to modeled count rates, Peak areas were normalized to a reference galactic comic ray flux value, sampled via the NS triple coincidence count, to a value of 26.5 triples/sec, and finally 4. Peak areas were empirically corrected to a constant (nadir) viewing geometry. See the following paper (Applicable Document 14) for further details on thermal neutron map generation:

Peplowski, Patrick N., David J. Lawrence, William C. Feldman, John O. Goldsten, David Bazell, Larry G. Evans, James W. Head, Larry R. Nittler, Sean C. Solomon, and Shoshana Z. Weider. "Geochemical terranes of Mercury's northern hemisphere as revealed by MESSENGER neutron measurements." Icarus 253 (2015): 346-363.

5.2.5 Enhanced GRS Overview

TBD.

5.3 *Data Processing*

5.3.1 Data Processing Level

Data processing levels mentioned in this document refer to PDS4 processing levels. Table 1 provides a description of these levels along with the equivalent designations used in other systems. All MEAP data products described in this document are derived data.

Table 1: Data processing level definitions

PDS4 processing level	PDS4 processing level description	CODMAC Level (used in PDS3)	NASA Level (used in PDS3)
Raw	Original data from an experiment. If compression, reformatting, packetization, or other translation has been applied to facilitate data transmission or storage, those processes are reversed so that the archived data are in a PDS approved archive format. Often call EDRs (Experimental Data Records).	1	0
Partially Processed	Data that have been processed beyond the raw stage but which have not yet reached calibrated status. These and more highly processed products are often called RDRs (Reduced Data Records).	2	1A
Calibrated	Data converted to physical units, which makes values independent of the experiment.	3	1B
Derived	Results that have been distilled from one or more calibrated data products (for example, maps, gravity or magnetic fields, or ring particle size distributions). Supplementary data, such as calibration tables or tables of viewing geometry, used to interpret observational data should also be classified as 'derived' data if not easily matched to one of the other three categories.	4+	2+

5.3.2 Data Product Generation

The VIRS and UVVS Cubes were produced at the Johns Hopkins University Applied Physics Laboratory (APL) and Applied Coherent Technologies (ACT). The NS DDR and GRS DAP and RDR files were produced at APL. All products are provided to the MEAP project and MESSENGER Science Operations Center (SOC) operated jointly by APL and ACT. APL is responsible for converting the data to the proper PDS labeled format. The MEAP data products are made available to the MEAP Team for initial evaluation and validation. At the end of the evaluation and validation period, the data are organized and stored on the best-determined media and made available to the PDS for distribution to the science community. These products will be used for direct science analysis, and construction of other science products.

5.3.3 Data Flow

The MEAP Project and Co-Is generate and validate data archives under the auspices of the MEAP PI. The MEAP personnel work with the MESSENGER SOC through ACT, and the PDS. A primary data server residing at the SOC, located at the Johns Hopkins University/Applied Physics Lab (JHU/APL), serves as a data storage facility for all MESSENGER archival data. For all MEAPs, APL has utilized Instrument EDR, CDR and DDR data from the SOC and PDS archives, derived the MEAPs from the data, and returned the data to the SOC for storage and distribution.

5.4 *Standards Used in Generating Data Products*

All MEAPs and labels comply with Planetary Data System standards, including the PDS4 data model, as specified in Applicable Documents 1, 2 and 3.

5.4.1 Coordinate Systems

The coordinate systems in use are: the celestial reference system for target and spacecraft position and velocity vectors and camera pointing and the planetary coordinate system for geometry vectors and target location. The celestial coordinate system is J2000 (Mean of Earth equator and equinox of J2000). The planetary coordinate system is planetocentric.

The list below describes the computational assumptions for the geometric and viewing data provided in the PDS label:

Latitudes and longitudes are planetocentric.

Distances are in km, speeds in km/sec, angles, in degrees, angular rates in degrees/sec, unless otherwise noted.

Angle ranges are 0 to 360 degrees for azimuths and local hour angle. Longitudes range from 0 to 360 degrees (positive to the East). Latitudes range from -90 to 90 degrees.

5.4.2 Geometric Elements

The timing and spatial information that is packaged with the MEAPs are the timing and spatial values derived from the appropriate SPICE kernels collected for each day of the mission. SPICE is an acronym for **S**pacecraft, **P**lanet, **I**nstrument, **C**-matrix, and **E**vent kernels. SPICE kernels are provided by the Navigational Ancillary Information Facility (NAIF) at the Jet Propulsion Laboratory, and are the standard for all timing and spatial data transformations.

5.4.3 Data Storage Conventions

5.4.3.1 The VIRS Cube

VIRS Cube DAPs are stored in binary IMG format. The wavelength file is in ASCII Table format.

The VIRS Cube DAPs are present in the VIRS directory within the IMAGECUBE collection. Within the VIRS directory, the DAPs are organized into subdirectories based on the Mercury Chart containing the DAP. Latitude and longitude limits of Mercury Charts, as named at the end of mission delivery, are:

Table 2: Mercury Chart definitions

Quadrangle	Subdirectory	Latitude (degrees)	Longitude (degrees east)
H-1 Borealis	H01	65 to 90	0 to 360
H-2 Victoria	H02	22.5 to 65	270 to 360
H-3 Shakespeare	H03	22.5 to 65	180 to 270
H-4 Raditladi	H04	22.5 to 65	90 to 180
H-5 Hokusai	H05	22.5 to 65	0 to 90
H-6 Kuiper	H06	-22.5 to 22.5	288 to 360
H-7 Beethoven	H07	-22.5 to 22.5	216 to 288
H-8 Tolstoj	H08	-22.5 to 22.5	144 to 216
H-9 Eminescu	H09	-22.5 to 22.5	72 to 144
H-10 Derain	H10	-22.5 to 22.5	0 to 72
H-11 Discovery	H11	-65 to -22.5	270 to 360
H-12 Michelangelo	H12	-65 to -22.5	180 to 270
H-13 Neruda	H13	-65 to -22.5	90 to 180
H-14 Debussey	H14	-65 to -22.5	0 to 90
H-15 Bach	H15	-90 to -65	0 to 360

5.4.3.2 The UVVS Cube

TBD.

5.4.3.3 The EETs

EETs are stored in ASCII Table format. The number of columns is determined by the number of parameters (22) recorded for each energetic event, and the number of records are determined by the number of events. There are 3 tables corresponding to different periods during MESSENGER's orbital mission.

NOTE 1: The MESSENGER spacecraft clock rolled over and was intentionally reset on 9 January 2013. As a consequence, the mission elapsed time (MET) clock jumps from large values prior to 9 January 2013 to small values on 9 January 2013. The latter times represent a new partition in the time-series dataset. More information about this issue is described in the file 'instrument_host.pdf' located in the document collection of this bundle.

NOTE 2: In a small number of cases, the periapsis latitude has values of 0. This is due to an artifact in the algorithm that determines this value. Since this value is determined by the spacecraft orbit, approximate periapsis latitude values can be determined by interpolating from the values of events located nearby in time.

Table 3: EET parameter definitions

Parameter	Description
Event number	Unique identifier for each EE event.
Event length	Duration of the event in number of 20-second accumulations.
Day of year	Day of year on which the 20-second accumulation occurs.
Month	Month in which the 20-second accumulation occurs.
Day	Day in month in which the 20-second accumulation occurs.
Year	Year in which the 20-second accumulation occurs.
Hour	Hour within the day in which the 20-second accumulation occurs.
Minute	Minute within the hour in which the 20-second accumulation occurs.
Second	Second within the minute in which the 20-second accumulation occurs.
MET	Mission elapsed time, and is the mission tag time in seconds of the start of the associated accumulated period. Times prior to 9 January 2013 are in the first MET partition; times on and after 9 January 2013 are in the second MET partition.
Orbit number	Orbit number is defined as starting at apoherm and is calculated using the MET value and the appropriate SPICE kernels. Orbit numbering does not start until MESSENGER performs

	the Mercury orbit insertion. Until that time the value for orbit number is 0.
Altitude	Spacecraft altitude above the subsatellite point on the target in units of km.
Latitude	Target-centric latitude of the spacecraft subsatellite point in degrees.
Longitude	Target-centric longitude of the spacecraft subsatellite point in degrees.
Local time	Local time of the spacecraft subsatellite point in hours from 0 to 24.
Beta angle	Angle of the normal of the spacecraft orbital plane with respect to Mercury-to-Sun vector in degrees.
Sun distance	Distance of the spacecraft to the Sun in units of km.
Periapsis latitude	Target-centric latitude of the spacecraft when it is at the periapsis (lowest) altitude for the given orbit number.
Event length, minutes	Length of the EE event in minutes. The value is repeated for 'Event Length' rows in the file.
Signal-to-noise	Event signal-to-noise, and is the measure of the size of the event within each 20-second accumulation.
BP total	Total counts within the Borated Plastic sensor 64-channel, 20-s spectral accumulation.
BP low	Total counts within the lowest 12 channels of the Borated Plastic sensor, 20-s spectral accumulation.

5.4.3.4 The TN Map

The TN Map is stored in two formats, IMG and JPEG2000. The image file has 259200 elements, which corresponds to the original 720 x 360 degree map (0.5 degree wide pixels in east longitude, latitude). The elements are arranged from the top (90 lat, -180 lon) across, then down (last entry is –90, 180). Each element is a byte. Pixel values range from 0 to 255, converting them to physical units (10^{-4} cm^2/g) requires multiplying the pixel value by 0.222860. Pixel values of zero are unmapped, and this corresponds to all latitudes less than (south) of 20 deg N.

5.4.3.5 The Enhanced GRS Dataset

TBD.

5.4.4 Data Validation

All MEAPs are validated by the MEAP Cognizant Co-Is for science content and for compliance with PDS archive standards. All MEAPs and documentation will be submitted to a peer review committee for science review according to PDS policy.

5.4.5 Software

The information in the PDS labels includes complete software-readable descriptions of data file formats, so that users may write custom software to read the products if desired.

6 MEAP Archive Organization, Identifiers and Naming Conventions

This section describes the basic organization of the MEAP data archive under the PDS4 Information Model (IM) (Applicable Documents 1 and 3), including the naming conventions used for the bundle, collection, and product unique identifiers. The formation of logical identifiers is described in section 4.1. Bundles, collections and products are defined in sections 6.2-6.4.

6.1 *Logical Identifiers*

Every product in PDS is assigned an identifier which allows it to be uniquely identified across the system. This identifier is referred to as a Logical Identifier or LID. A LIDVID (Versioned Logical Identifier) includes product version information, and allows different versions of a specific product to be referenced uniquely. A product's LID and VID are defined as separate attributes in the product label. LIDs and VIDs are assigned by PDS and are formed according to the conventions described in the following sections. The uniqueness of a product's LIDVID may be verified using the PDS Registry and Harvest tools. More information on LIDs and VIDs may be found in section 6d of the PDS Standards Reference (Applicable Document 1) and in chapter 5 of the Data Providers' Handbook (Applicable Document 4).

6.1.1 LID Formation

LIDs take the form of a Uniform Resource Name (URN). LIDs are restricted to ASCII lower case letters, digits, dash, underscore, and period. Colons are also used, but only to separate prescribed components of the LID. Within one of these prescribed components dash, underscore, or period are used as separators. LIDs are limited in length to 255 characters.

MEAP LIDs are formed according to the following conventions:

- Bundle LIDs are formed by appending a bundle specific ID to the PDS base ID:

    urn:nasa:pds:<bundle ID>
    Example: urn:nasa:pds:izenberg_pdart14_meap

  The bundle ID must be unique across all bundles archived with the PDS.
- Collection LIDs are formed by appending a collection specific ID to the collection's parent bundle LID:

    urn:nasa:pds:<bundle ID>:<collection ID>
    Example: urn:nasa:pds:izenberg_pdart14_meap:data_tnmap

  Since the collection LID is based on the bundle LID, which is unique across PDS, the only additional condition is that the collection ID must be unique across the bundle. Collection IDs correspond to the collection type (e.g. "data", "document", etc.). Additional descriptive information may be appended to the collection type (e.g. “data_raw”, “data_calibrated”, etc.) to insure that multiple collections of the same type within a single bundle have unique LIDs.

- Basic product LIDs are formed by appending a product-specific ID to the product’s parent collection LID:

  urn:nasa:pds:<bundle ID>:<collection ID>:<product ID>
  Example:
  urn:nasa:pds:izenberg_pdart14_meap:data_tnmap:thermal_neutron_map

  Since the product LID is based on the collection LID, which is unique across PDS, the only additional condition is that the product ID must be unique across the collection. For MEAP data products, the product LID is the same as the data file name without the extension.

6.1.2 VID Formation

Product Version IDs consist of major and minor components separated by a “.” (M.n). Both components of the VID are integer values. The major component is initialized to a value of “1”, and the minor component is initialized to a value of “0”. The minor component resets to “0” when the major component is incremented. The PDS Standards Reference 1 specifies rules for incrementing major and minor components.

6.1.3 File Naming Convention

The MEAP-1 DAPs are named:
“VIRS_CUBE_64PPD_HXXDD.IMG”
where XX is Mercury chart, and DD is quadrant within the chart.

The MEAP-1 wavelength file is named:
“VIRS_WAVELENGTHS.TAB”
and is an ASCII file 2 columns by 105 records long with the layer numbers and wavelengths of the spectral layers of the VIRS Cube.

The MEAP-2 DAP names are TBD.

The MEAP-3 EETs are named:
“ELE_EVT_12HR_ORBIT_2011-2012.TAB”
This is data from the 12-hour orbit, taken during 2011 and 2012.
“ELE_EVT_8HR_ORBIT_2012-2013.TAB”
This is data taken from the 8-hour orbit, taken during 2012 and 2013. The data from 2011 to 2013 encompasses the entire dataset reported in Lawrence et al. (2015) and contains 2711 events.
“ELE_EVT_8HR_ORBIT_2014-2015.TAB”
This is data taken from the 8-hour orbit in the years 2014 and 2015. This contains an additional 1400 events. The total number of detected EE events for the mission is therefore 2711 + 1400 = 4111.

The MEAP-4 thermal neutron map is named:

"THERMAL_NEUTRON_MAP.XXX", where the file extension, ".XXX" is either IMG or jpeg2000 (JP2).

The MEAP-5 DDR names are TBD.

6.2 *Bundles*

The highest level of organization for a PDS archive is the bundle. A bundle is a set of one or more related collections which may be of different types. A collection is a set of one or more related basic products which are all of the same type. Bundles and collections are logical structures, not necessarily tied to any physical directory structure or organization.

The complete MEAP archive is organized into 1 bundle: urn:nasa:pds:izenberg_pdart14_meap.

6.3 *Collections*

Collections consist of basic products all of the same type. The MEAP Bundle contains the collections listed in Table 4.

Table 4: Collections in the MEAP Bundle

Collection Logical Identifier	Collection Type	Description
urn:nasa:pds:izenberg_pdart14_meap:data_tnmap	Image file in standard PDS4 IMG format with supplemental image file in JPEG2000 format.	Izenberg PDART 2014 MESSENGER Advanced Products Thermal Neutron Map Collection
urn:nasa:pds:izenberg_pdart14_meap:data_imagecube	Image files in standard PDS4 IMG format.	Izenberg PDART 2014 MESSENGER Advanced Products Image Cube Collection
urn:nasa:pds:izenberg_pdart14_meap:data_eetable	ASCII tables in standard PDS4 TAB format.	Izenberg PDART 2014 MESSENGER Advanced Products Energetic Electrons Table Collection
urn:nasa:pds:izenberg_pdart14_meap:data_grsspectra	TBD.	Izenberg PDART 2014 MESSENGER

		Advanced Products GRS Spectra Collection
urn:nasa:pds:izenberg_pdart14_meap:document	Document files in PDF/A format.	Izenberg PDART 2014 MESSENGER Advanced Products Document Collection

6.4 *Products*

A PDS product consists of one or more digital objects and an accompanying PDS label file. PDS labels provide identification and description information for labeled objects. The PDS label includes a Logical Identifier (LID) by which any PDS labeled product is uniquely identified throughout all PDS archives. PDS4 labels are XML-formatted ASCII files.

The LID for a product in all the Collections consists of the collection LID concatenated with the file name, without the extension.
Example LID for the thermal neutron map product:
urn:nasa:pds:izenberg_pdart14_meap:data_tnmap:thermal_neutron_map.

6.5 *Document Collection*

Documents are also considered products by PDS, and have LIDs, VIDs and PDS4 labels just as data products do. The MEAP bundle includes a Document Collection, which consists of documents relevant to the MESSENGER mission and its instruments, as well as the Specification documents for each of the data product collections.

Table 5: Documents in the MEAP Document Collection

Product Logical Identifier	Description
urn:nasa:pds:izenberg_pdart14_meap:document:meap	MEAP Specification (the document you're reading)
urn:nasa:pds:izenberg_pdart14_meap:document:mission	MESSENGER mission description
urn:nasa:pds:izenberg_pdart14_meap:document:instrument_host	MESSENGER spacecraft description
urn:nasa:pds:izenberg_pdart14_meap:document:grs_inst	GRS instrument description
urn:nasa:pds:izenberg_pdart14_meap:document:ns_inst	NS instrument description
urn:nasa:pds:izenberg_pdart14_meap:document:mascs_inst	MASCS instrument description

7 MEAP Formats

Data that comprise the MEAP archive are formatted in accordance with PDS specifications (see Applicable Documents [1], [2], and [3]). This section provides details on the formats used for each of the products included in the archive.

7.1 *VIRS Cube Data Product Format*

VIRS Cubes are stored in Binary format.

A VIRS Cube DAP:

- Consists of map-projected photometrically normalized I/F DDRs mosaicked into a hyperspectral map tile. Individual footprint pixels where VIRS data exists are determined by 'best' VIRS spectra, determined by a quality factor using favorable geometry (max (cos (e) * cos(i))) and spatial coverage (smaller footprints are given higher quality factor). All hyperspectral data

- Contains VIRS spectral data in I/F corrected photometrically to i=45 degrees, e=45, phase angle 90 degrees, at a resolution of 64 pixels per degree (~665 m/pixel at the equator);

- Represents one latitude-longitude bin in a hyperspectral cube;

- Is composed of up to 105 spectral bands corresponding to 105 binned wavelengths of the VIRS spectrum from 300 to 1450 nm, with ~9.3 nm wavelength bins between 300 and 900 nm and ~14 nm wavelength bins between 900 and 1450 nm.

- 8 backplanes for the hyperspectral data:

(a) incidence angle of the original spectrum, (b) emission angle of the original spectrum, (c) phase angle of the original spectrum, (d) observation area of the VIRS spectrum (e) Temperature of the NIR detector (f) CDR Date (YYDOY) of VIRS observation (g) CDR time (HHMMSS) of VIRS observation (h) CDR Spectrum number of VIRS observation.

An example label is given in Appendix B.

7.2 *UVVS Cube Data Product Format*

TBD.

7.3 *Energetic Event Table Data Product Format*

EETs are stored in ASCII Table format. The number of columns is determined by the number of parameters (22) recorded for each energetic event, and the number of records are determined by the number of events. There are 3 tables corresponding to different periods during MESSENGER's orbital mission:

- 12-hr orbit, 2011-2012: This is data from the 12-hour orbit, taken during 2011 and 2012.
- 8-hr orbit, 2012-2013: This is data taken from the 8-hour orbit, taken during 2012 and 2013. The data from 2011 to 2013 encompasses the entire dataset reported in Lawrence et al. (2015) and contains 2711 events.

- 8-hr orbit, 2014-2015: This is data taken from the 8-hour orbit in the years 2014 and 2015. This contains an additional 1400 events. The total number of detected EE events for the mission is therefore 2711 + 1400 = 4111.

An example label is given in Appendix B.

7.4 *Thermal Neutron Map Data Product Format*

The thermal neutron map is stored in two formats, IMG and JPEG2000. The JPEG2000 version is considered a supplemental product. The PDS4 label describes both versions of the data product.

The image file has 259200 elements, which corresponds to the original 720 x 360 degree map (0.5 degree wide pixels in east longitude, latitude). The elements are arranged from the top (90 lat, -180 lon) across, then down (last entry is –90, 180). Each element is a byte. Pixel values range from 0 to 255, converting them to physical units (10^{-4} cm^2/g) requires multiplying the pixel value by 0.222860. Pixel values of zero are unmapped, and this corresponds to all latitudes less than (south) of 20 deg N.

An example label is given in Appendix B.

7.5 *GRS Enhanced Data Set Data Product Format*

TBD.

7.6 *Document Product Formats*

Documents in this archive are provided as PDF/A (www.pdfa.org/download/pdfa-in-a-nutshell) or as plain ASCII text if no special formatting is required. Figures that accompany documents may be embedded in the PDF/A files or provided as separate TIFF, GIF, JPEG, or PNG files.

7.7 *PDS Labels*

Each MEAP product is accompanied by a PDS4 label. PDS4 labels are ASCII text files written in the eXtensible Markup Language (XML). Product labels are detached from the files they describe (with the exception of the Product_Bundle label). There is one label for every product. A PDS4 label file usually has the same name as the data product it describes, but always with the extension ".xml".

For the MEAP archive, the structure and content of PDS labels conforms to the PDS master schema and schematron based upon the PDS Information Model 1.5.0.0. By use of an XML editor the schema and schematron may be used to validate the structure and content of the product labels. In brief, the schema is the XML model that PDS4 labels must follow, and the schematron is a set of validation rules that are applied to PDS4 labels.

The PDS master schema and schematron documents are produced, managed, and supplied by the PDS.

Sample PDS labels for the MEAP data products are shown in Appendix B.

8 Appendix A- Glossary

Many of these definitions are taken from Appendix A of the PDS4 Concepts Document, pds.nasa.gov/pds4/doc/concepts. The reader is referred to that document for more information.

Archive – A place in which public records or historical documents are preserved; also the material preserved – often used in plural. The term may be capitalized when referring to all of PDS holdings – the PDS Archive.

Basic Product – The simplest product in PDS4; one or more data objects (and their description objects), which constitute (typically) a single observation, document, etc. The only PDS4 products that are *not* basic products are collection and bundle products.

Bundle Product – A list of related collections. For example, a bundle could list a collection of raw data obtained by an experiment during its mission lifetime, a collection of the calibration products associated with the experiment, and a collection of all documentation relevant to the first two collections.

Class – The set of attributes (including a name and identifier) which describes an item defined in the PDS Information Model. A class is generic – a template from which individual items may be constructed.

Collection Product – A list of closely related basic products of a single type (e.g. observational data, browse, documents, etc.). A collection is itself a product (because it is simply a list, with its label), but it is not a *basic* product.

Data Object – A generic term for an object that is described by a description object. Data objects include both digital and non-digital objects.

Description Object – An object that describes another object. As appropriate, it will have structural and descriptive components. In PDS4 a 'description object' is a digital object – a string of bits with a predefined structure.

Digital Object – An object which consists of real electronically stored (digital) data.

Identifier – A unique character string by which a product, object, or other entity may be identified and located. Identifiers can be global, in which case they are unique across all of PDS (and its federation partners). A local identifier must be unique within a label.

Label – The aggregation of one or more description objects such that the aggregation describes a single PDS product. In the PDS4 implementation, labels are constructed using XML.

Logical Identifier (**LID**) – An identifier which identifies the set of all versions of a product.

Versioned Logical Identifier (LIDVID) – The concatenation of a logical identifier with a version identifier, providing a unique identifier for each version of product.

Manifest - A list of contents.

Metadata – Data about data – for example, a 'description object' contains information (metadata) about an 'object.'

Object – A single instance of a class defined in the PDS Information Model.

PDS Information Model – The set of rules governing the structure and content of PDS metadata. While the Information Model (IM) has been implemented in XML for PDS4, the model itself is implementation independent.

Product – One or more tagged objects (digital, non-digital, or both) grouped together and having a single PDS-unique identifier. In the PDS4 implementation, the descriptions are combined into a single XML label. Although it may be possible to locate individual objects within PDS (and to find specific bit strings within digital objects), PDS4 defines 'products' to be the smallest granular unit of addressable data within its complete holdings.

Tagged Object – An entity categorized by the PDS Information Model, and described by a PDS label.

Registry – A data base that provides services for sharing content and metadata.

Repository – A place, room, or container where something is deposited or stored (often for safety).

XML – eXtensible Markup Language.

XML schema – The definition of an XML document, specifying required and optional XML elements, their order, and parent-child relationships.

9 Appendix B- MEAP PDS Label Files (to be updated)

9.1 *VIRS Cube*

9.1.1 Tile file

```xml
<?xml version="1.0" encoding="UTF-8"?>
<?xml-model href="https://pds.nasa.gov/pds4/pds/v1/PDS4_PDS_1700.sch"
schematypens="http://purl.oclc.org/dsdl/schematron"?>
<?xml-model href="https://pds.nasa.gov/pds4/disp/v1/PDS4_DISP_1700.sch"
schematypens="http://purl.oclc.org/dsdl/schematron"?>
<?xml-model href="https://pds.nasa.gov/pds4/sp/v1/PDS4_SP_1100.sch"
schematypens="http://purl.oclc.org/dsdl/schematron"?>
<?xml-model href="http://pds.nasa.gov/pds4/cart/v1/PDS4_CART_1700.sch"
schematypens="http://purl.oclc.org/dsdl/schematron"?>

<Product_Observational xmlns="http://pds.nasa.gov/pds4/pds/v1"
    xmlns:disp="http://pds.nasa.gov/pds4/disp/v1"
    xmlns:sp="http://pds.nasa.gov/pds4/sp/v1"
    xmlns:cart="http://pds.nasa.gov/pds4/cart/v1"
    xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
    xsi:schemaLocation="
    http://pds.nasa.gov/pds4/pds/v1 https://pds.nasa.gov/pds4/pds/v1/PDS4_PDS_1700.xsd
    http://pds.nasa.gov/pds4/disp/v1 https://pds.nasa.gov/pds4/disp/v1/PDS4_DISP_1700.xsd
    http://pds.nasa.gov/pds4/sp/v1 https://pds.nasa.gov/pds4/sp/v1/PDS4_SP_1100.xsd
    http://pds.nasa.gov/pds4/cart/v1
http://pds.nasa.gov/pds4/cart/v1/PDS4_CART_1700.xsd">

    <Identification_Area>
        <!-- A product is one multiband image tile. 54 tiles cover the whole planet. -->

<logical_identifier>urn:nasa:pds:izenberg_pdart14_meap:data_imagecube:virs_cube_64ppd_h01
np</logical_identifier>
        <version_id>1.0</version_id>
        <title>VIRS Spectral Cube of Mercury Tile 01NP</title>
        <information_model_version>1.7.0.0</information_model_version>
        <product_class>Product_Observational</product_class>
    </Identification_Area>

    <Observation_Area>
        <Time_Coordinates>
            <start_date_time>2004-08-13Z</start_date_time>
            <stop_date_time>2015-04-30Z</stop_date_time>
        </Time_Coordinates>
        <Investigation_Area>
            <name>MESSENGER</name>
            <type>Mission</type>
            <Internal_Reference>

<lid_reference>urn:nasa:pds:context:investigation:mission.messenger</lid_reference>
                <reference_type>data_to_investigation</reference_type>
            </Internal_Reference>
        </Investigation_Area>
        <Observing_System>
            <name>MESSENGER MASCS</name>
            <Observing_System_Component>
                <name>MESSENGER</name>
                <type>Spacecraft</type>
                <Internal_Reference>

<lid_reference>urn:nasa:pds:context:instrument_host:spacecraft.mess</lid_reference>
                    <reference_type>is_instrument_host</reference_type>
                </Internal_Reference>
            </Observing_System_Component>
            <Observing_System_Component>
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                <type>Instrument</type>
                <Internal_Reference>

<lid_reference>urn:nasa:pds:context:instrument:mascs.mess</lid_reference>
                    <reference_type>is_instrument</reference_type>
                </Internal_Reference>
            </Observing_System_Component>
        </Observing_System>
        <Target_Identification>
            <name>Mercury</name>
            <type>Planet</type>
            <Internal_Reference>
                <lid_reference>urn:nasa:pds:context:target:planet.mercury</lid_reference>
                <reference_type>data_to_target</reference_type>
            </Internal_Reference>
        </Target_Identification>

        <Discipline_Area>

            <disp:Display_Settings>
                <Local_Internal_Reference>
```

```
<local_identifier_reference>Spectral_Cube_Object</local_identifier_reference>

<local_reference_type>display_settings_to_array</local_reference_type>
                </Local_Internal_Reference>
                <disp:Display_Direction>
                    <disp:horizontal_display_axis>Sample</disp:horizontal_display_axis>
                    <disp:horizontal_display_direction>Left to
Right</disp:horizontal_display_direction>
                    <disp:vertical_display_axis>Line</disp:vertical_display_axis>
                    <disp:vertical_display_direction>Top to
Bottom</disp:vertical_display_direction>
                </disp:Display_Direction>
            </disp:Display_Settings>

            <sp:Spectral_Characteristics>
                <sp:bin_width_desc>Bin width is a straightforward average of several
                    spectral pixels of VIRS DDR (4 pixels for VIS detector, six for
                    NIR, resulting in spectral bins about 9.4 nm across for VIS
                    detector, and about 14 nm across for the NIR detector. For the bin
                    width info of each spectral pixel, see the VIRS CDR/DDR/DAP SIS.
                </sp:bin_width_desc>
                <sp:Local_Internal_Reference>

<sp:local_identifier_reference>Spectral_Cube_Object</sp:local_identifier_reference>

<sp:local_reference_type>spectral_characteristics_to_array_object</sp:local_reference_typ
e>
                </sp:Local_Internal_Reference>
                <sp:Spectral_Lookup>
                    <sp:Local_Internal_Reference>

<sp:local_identifier_reference>VIRS_Wavelength_File</sp:local_identifier_reference>

<sp:local_reference_type>spectral_characteristics_to_bin_center_values</sp:local_referenc
e_type>
                    </sp:Local_Internal_Reference>
                    <sp:Internal_Reference>

<lid_reference>urn:nasa:pds:izenberg_pdart14_meap:imagecube:virs_wavelengths</lid_referen
ce>
                        <reference_type>data_to_ancillary_data</reference_type>
                    </sp:Internal_Reference>
                </sp:Spectral_Lookup>
            </sp:Spectral_Characteristics>

            <cart:Cartography>
                <cart:Spatial_Domain>
                    <cart:Bounding_Coordinates>
                        <cart:west_bounding_coordinate unit="deg">-
180.000000</cart:west_bounding_coordinate>
                        <cart:east_bounding_coordinate
unit="deg">180.000000</cart:east_bounding_coordinate>
                        <cart:north_bounding_coordinate
unit="deg">90.000000</cart:north_bounding_coordinate>
                        <cart:south_bounding_coordinate
unit="deg">64.000000</cart:south_bounding_coordinate>
                    </cart:Bounding_Coordinates>
                </cart:Spatial_Domain>
                <cart:Spatial_Reference_Information>
                    <cart:Horizontal_Coordinate_System_Definition>
                        <cart:Planar>
                            <cart:Map_Projection>
                                <cart:map_projection_name>Polar
Stereographic</cart:map_projection_name>
                                <cart:Polar_Stereographic>
                                    <cart:longitude_of_central_meridian
unit="deg">0.00</cart:longitude_of_central_meridian>
                                    <cart:latitude_of_projection_origin
unit="deg">90</cart:latitude_of_projection_origin>
                                </cart:Polar_Stereographic>
                            </cart:Map_Projection>
                            <cart:Planar_Coordinate_Information>
                                <cart:planar_coordinate_encoding_method>Coordinate
Pair</cart:planar_coordinate_encoding_method>
                                <cart:Coordinate_Representation>
                                    <cart:pixel_resolution_x
unit="m/pixel">665.107606</cart:pixel_resolution_x>
                                    <cart:pixel_resolution_y
unit="m/pixel">665.107606</cart:pixel_resolution_y>
```

```
                                    <cart:pixel_scale_x
unit="pixel/deg">64.013043</cart:pixel_scale_x>
                                    <cart:pixel_scale_y
unit="pixel/deg">64.013043</cart:pixel_scale_y>
                                </cart:Coordinate_Representation>
                            </cart:Planar_Coordinate_Information>
                            <cart:Geo_Transformation>
                                <cart:upperleft_corner_x unit="m">-
1126359.730863</cart:upperleft_corner_x>
                                <cart:upperleft_corner_y
unit="m">1126359.730863</cart:upperleft_corner_y>
                            </cart:Geo_Transformation>
                        </cart:Planar>
                        <cart:Geodetic_Model>
                            <cart:latitude_type>planetocentric</cart:latitude_type>
                            <cart:spheroid_name>Mercury</cart:spheroid_name>
                            <cart:semi_major_radius
unit="km">2439.4</cart:semi_major_radius>
                            <cart:semi_minor_radius
unit="km">2439.4</cart:semi_minor_radius>
                            <cart:polar_radius unit="km">2439.4</cart:polar_radius>
                            <cart:longitude_direction>Positive
East</cart:longitude_direction>
                        </cart:Geodetic_Model>
                    </cart:Horizontal_Coordinate_System_Definition>
                </cart:Spatial_Reference_Information>
            </cart:Cartography>

        </Discipline_Area>
    </Observation_Area>

    <File_Area_Observational>
        <File>
            <file_name>virs_cube_64ppd_h01np.img</file_name>
            <creation_date_time>2016-05-04T23:55:10</creation_date_time>
            <file_size unit="byte">5185239588</file_size>
            <comment>VIRS Image Cube Tile 01NP in standard PDS4 IMG format.
                     The image cube has 105 spectral bands and 8 backplanes.</comment>
        </File>

        <!-- Image Cube Core -->
        <Array_3D_Spectrum>
            <name>VIRS Image Cube Tile 01NP</name>
            <local_identifier>Spectral_Cube_Object</local_identifier>
            <offset unit="byte">0</offset>
            <axes>3</axes>
            <axis_index_order>Last Index Fastest</axis_index_order>
            <description>The core of the image cube has 105 spectral bands with center
                wavelengths from 303 to 1448 nanometers. Wavelengths are given
                in the VIRS Wavelength file. Bands have 3387 lines and 3387
                4-byte floating-point pixels per line. Bands are stored
                sequentially in the cube.</description>
            <Element_Array>
                <!-- Pixels are floating-point, 4-byte, single-precision, LSB ("Intel")
values -->
                <data_type>IEEE754LSBSingle</data_type>
                <unit>Reflectance</unit>
            </Element_Array>
            <Axis_Array>
                <axis_name>Band</axis_name>
                <elements>105</elements>
                <sequence_number>1</sequence_number>
            </Axis_Array>
            <Axis_Array>
                <axis_name>Line</axis_name>
                <elements>3387</elements>
                <sequence_number>2</sequence_number>
            </Axis_Array>
            <Axis_Array>
                <axis_name>Sample</axis_name>
                <elements>3387</elements>
                <sequence_number>3</sequence_number>
            </Axis_Array>
            <Special_Constants>
                <missing_constant>-999.0</missing_constant>
            </Special_Constants>
        </Array_3D_Spectrum>

        <!-- Backplane 1 -->
        <Array_2D_Image>
            <name>Incidence Angle</name>
```

```
            <offset unit="byte">4818142980</offset> <!-- 105 bands * lines * samples * 4
bytes -->
            <axes>2</axes>
            <axis_index_order>Last Index Fastest</axis_index_order>
            <description>The Incidence Angle backplane contains the incidence angle of
                MASCS/VIRS observations used in cube</description>
            <Element_Array>
                <!-- Pixels are floating-point, 4-byte, single-precision, LSB ("Intel")
values -->
                <data_type>IEEE754LSBSingle</data_type>
                <unit>degree</unit>
            </Element_Array>
            <Axis_Array>
                <axis_name>Line</axis_name>
                <elements>3387</elements>
                <sequence_number>1</sequence_number>
            </Axis_Array>
            <Axis_Array>
                <axis_name>Sample</axis_name>
                <elements>3387</elements>
                <sequence_number>2</sequence_number>
            </Axis_Array>
        </Array_2D_Image>

        <!-- Backplane 2 -->
        <Array_2D_Image>
            <name>Emission Angle</name>
            <offset unit="byte">4864030056</offset> <!-- 106 bands * lines * samples * 4
bytes -->
            <axes>2</axes>
            <axis_index_order>Last Index Fastest</axis_index_order>
            <description>The Emission Angle backplane contains the emission angle of
                MASCS/VIRS observations used in cube</description>
            <Element_Array>
                <!-- Pixels are floating-point, 4-byte, single-precision, LSB ("Intel")
values -->
                <data_type>IEEE754LSBSingle</data_type>
                <unit>degree</unit>
            </Element_Array>
            <Axis_Array>
                <axis_name>Line</axis_name>
                <elements>3387</elements>
                <sequence_number>1</sequence_number>
            </Axis_Array>
            <Axis_Array>
                <axis_name>Sample</axis_name>
                <elements>3387</elements>
                <sequence_number>2</sequence_number>
            </Axis_Array>
        </Array_2D_Image>

        <!-- Backplane 3 -->
        <Array_2D_Image>
            <name>Phase Angle</name>
            <offset unit="byte">4909917132</offset> <!-- 107 bands * lines * samples * 4
bytes -->
            <axes>2</axes>
            <axis_index_order>Last Index Fastest</axis_index_order>
            <description>The Phase Angle backplane contains the phase angle of
                MASCS/VIRS observations used in cube</description>
            <Element_Array>
                <!-- Pixels are floating-point, 4-byte, single-precision, LSB ("Intel")
values -->
                <data_type>IEEE754LSBSingle</data_type>
                <unit>deg</unit>
            </Element_Array>
            <Axis_Array>
                <axis_name>Line</axis_name>
                <elements>3387</elements>
                <sequence_number>1</sequence_number>
            </Axis_Array>
            <Axis_Array>
                <axis_name>Sample</axis_name>
                <elements>3387</elements>
                <sequence_number>2</sequence_number>
            </Axis_Array>
        </Array_2D_Image>

        <!-- Backplane 4 -->
        <Array_2D_Image>
            <name>Observation Area</name>
```

```
            <offset unit="byte">4955804208</offset> <!-- 108 bands * lines * samples * 4
bytes -->
            <axes>2</axes>
            <axis_index_order>Last Index Fastest</axis_index_order>
            <description>The Observation Area backplane contains the area of
                MASCS/VIRS observations used in cube</description>
            <Element_Array>
                <!-- Pixels are floating-point, 4-byte, single-precision, LSB ("Intel")
values -->
                <data_type>IEEE754LSBSingle</data_type>
                <unit>km**2</unit>
            </Element_Array>
            <Axis_Array>
                <axis_name>Line</axis_name>
                <elements>3387</elements>
                <sequence_number>1</sequence_number>
            </Axis_Array>
            <Axis_Array>
                <axis_name>Sample</axis_name>
                <elements>3387</elements>
                <sequence_number>2</sequence_number>
            </Axis_Array>
        </Array_2D_Image>

        <!-- Backplane 5 -->
        <Array_2D_Image>
            <name>NIR Temperature</name>
            <offset unit="byte">5001691284</offset> <!-- 109 bands * lines * samples * 4
bytes -->
            <axes>2</axes>
            <axis_index_order>Last Index Fastest</axis_index_order>
            <description>The NIR Temperature backplane contains the NIR detector
                temperature of MASCS/VIRS observations used in cube</description>
            <Element_Array>
                <!-- Pixels are floating-point, 4-byte, single-precision, LSB ("Intel")
values -->
                <data_type>IEEE754LSBSingle</data_type>
                <unit>degC</unit>
            </Element_Array>
            <Axis_Array>
                <axis_name>Line</axis_name>
                <elements>3387</elements>
                <sequence_number>1</sequence_number>
            </Axis_Array>
            <Axis_Array>
                <axis_name>Sample</axis_name>
                <elements>3387</elements>
                <sequence_number>2</sequence_number>
            </Axis_Array>
        </Array_2D_Image>

        <!-- Backplane 6 -->
        <Array_2D_Image>
            <name>Source CDR Date</name>
            <offset unit="byte">5047578360</offset> <!-- 110 bands * lines * samples * 4
bytes -->
            <axes>2</axes>
            <axis_index_order>Last Index Fastest</axis_index_order>
            <description>The Source CDR Date backplane contains the CDR Date of
                MASCS/VIRS observations used in cube.
                Date is encoded in the integer part of the real value as YYDOY.
                The CDR date, CDR time can be used to find the CDR/DDR file where the
observation
                source data is stored, while the spectrum number can be used to find the
CDR/DDR
                record associated to the observation.</description>
            <Element_Array>
                <!-- Pixels are floating-point, 4-byte, single-precision, LSB ("Intel")
values -->
                <data_type>IEEE754LSBSingle</data_type>
            </Element_Array>
            <Axis_Array>
                <axis_name>Line</axis_name>
                <elements>3387</elements>
                <sequence_number>1</sequence_number>
            </Axis_Array>
            <Axis_Array>
                <axis_name>Sample</axis_name>
                <elements>3387</elements>
                <sequence_number>2</sequence_number>
            </Axis_Array>
```

```
        </Array_2D_Image>

        <!-- Backplane 7 -->
        <Array_2D_Image>
            <name>Source CDR Time</name>
            <offset unit="byte">5093465436</offset> <!-- 111 bands * lines * samples * 4
bytes -->
            <axes>2</axes>
            <axis_index_order>Last Index Fastest</axis_index_order>
            <description>The Source CDR Time backplane contains the CDR Time of
                MASCS/VIRS observations used in cube.
                Time is encoded in the integer part of the real value as HHMMSS.
                The CDR date, CDR time can be used to find the CDR/DDR file where the
observation
                source data is stored, while the spectrum number can be used to find the
CDR/DDR
                record associated to the observation.</description>
            <Element_Array>
                <!-- Pixels are floating-point, 4-byte, single-precision, LSB ("Intel")
values -->
                <data_type>IEEE754LSBSingle</data_type>
            </Element_Array>
            <Axis_Array>
                <axis_name>Line</axis_name>
                <elements>3387</elements>
                <sequence_number>1</sequence_number>
            </Axis_Array>
            <Axis_Array>
                <axis_name>Sample</axis_name>
                <elements>3387</elements>
                <sequence_number>2</sequence_number>
            </Axis_Array>
        </Array_2D_Image>

        <!-- Backplane 8 -->
        <Array_2D_Image>
            <name>Source CDR Spectrum Number</name>
            <offset unit="byte">5139352512</offset> <!-- 112 bands * lines * samples * 4
bytes -->
            <axes>2</axes>
            <axis_index_order>Last Index Fastest</axis_index_order>
            <description>The Source CDR Spectrum Number backplane contains the spectrum
number of
                MASCS/VIRS observations used in cube.
                The CDR date, CDR time can be used to find the CDR/DDR file where the
observation
                source data is stored, while the spectrum number can be used to find the
CDR/DDR
                record associated to the observation.</description>
            <Element_Array>
                <!-- Pixels are floating-point, 4-byte, single-precision, LSB ("Intel")
values -->
                <data_type>IEEE754LSBSingle</data_type>
            </Element_Array>
            <Axis_Array>
                <axis_name>Line</axis_name>
                <elements>3387</elements>
                <sequence_number>1</sequence_number>
            </Axis_Array>
            <Axis_Array>
                <axis_name>Sample</axis_name>
                <elements>3387</elements>
                <sequence_number>2</sequence_number>
            </Axis_Array>
        </Array_2D_Image>

    </File_Area_Observational>

    <File_Area_Observational_Supplemental>
        <File>
            <file_name>virs_cube_64ppd_h01np.hdr</file_name>
            <comment>Supplemental information used to display image with ENVI commercial
software</comment>
        </File>
        <Stream_Text>
            <offset unit="byte">0</offset>
            <parsing_standard_id>7-Bit ASCII Text</parsing_standard_id>
            <record_delimiter>Carriage-Return Line-Feed</record_delimiter>
        </Stream_Text>
    </File_Area_Observational_Supplemental>
```

```
</Product_Observational>
```


9.1.2 Wavelength file


```
<?xml version="1.0" encoding="UTF-8"?>
<?xml-model href="http://pds.nasa.gov/pds4/pds/v1/PDS4_PDS_1700.sch"
schematypens="http://purl.oclc.org/dsdl/schematron"?>
<Product_Ancillary xmlns="http://pds.nasa.gov/pds4/pds/v1"
    xmlns:pds="http://pds.nasa.gov/pds4/pds/v1"
    xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
    xsi:schemaLocation="http://pds.nasa.gov/pds4/pds/v1
http://pds.nasa.gov/pds4/pds/v1/PDS4_PDS_1700.xsd">
    <Identification_Area>

<logical_identifier>urn:nasa:pds:izenberg_pdart14_meap:data_imagecube:virs_wavelengths</l
ogical_identifier>
        <version_id>1.0</version_id>
        <title>Wavelength centers of VIRS Spectral Cube bands</title>
        <information_model_version>1.7.0.0</information_model_version>
        <product_class>Product_Ancillary</product_class>
    </Identification_Area>
    <Context_Area>
        <comment>Band widths are different for VIS detector and NIR detector. VIS
detector bands (shortward of 900 nm)
            are averages of 4 VIS detector pixels with total bandwidth of ~9.3 nm per
band.
            NIR bands are averages of 6 NIR detector pixels with bandwidths of ~14.0 nm
per band.
        </comment>
        <Time_Coordinates>
            <start_date_time>2004-08-13Z</start_date_time>
            <stop_date_time>2015-04-30Z</stop_date_time>
        </Time_Coordinates>
        <Investigation_Area>
            <name>MESSENGER</name>
            <type>Mission</type>
            <Internal_Reference>

<lid_reference>urn:nasa:pds:context:investigation:mission.messenger</lid_reference>
                <reference_type>data_to_investigation</reference_type>
            </Internal_Reference>
        </Investigation_Area>
        <Observing_System>
            <name>MESSENGER MASCS</name>
            <Observing_System_Component>
                <name>MESSENGER</name>
                <type>Spacecraft</type>
                <Internal_Reference>

<lid_reference>urn:nasa:pds:context:instrument_host:spacecraft.mess</lid_reference>
                    <reference_type>is_instrument_host</reference_type>
                </Internal_Reference>
            </Observing_System_Component>
            <Observing_System_Component>
                <name>MASCS</name>
                <type>Instrument</type>
                <Internal_Reference>

<lid_reference>urn:nasa:pds:context:instrument:mascs.mess</lid_reference>
                    <reference_type>is_instrument</reference_type>
                </Internal_Reference>
            </Observing_System_Component>
        </Observing_System>
        <Target_Identification>
            <name>Mercury</name>
            <type>Planet</type>
            <Internal_Reference>
                <lid_reference>urn:nasa:pds:context:target:planet.mercury</lid_reference>
                <reference_type>collection_to_target</reference_type>
            </Internal_Reference>
        </Target_Identification>
    </Context_Area>
    <File_Area_Ancillary>
        <File>
            <file_name>virs_wavelengths.tab</file_name>
            <local_identifier>VIRS_Wavelength_File</local_identifier>
            <creation_date_time>2016-04-19T18:07:00</creation_date_time>
        </File>
```

```
        <Table_Character>
            <offset unit="byte">0</offset>
            <records>105</records>
            <record_delimiter>Carriage-Return Line-Feed</record_delimiter>
            <Record_Character>
                <fields>2</fields>
                <groups>0</groups>
                <record_length unit="byte">10</record_length>
                <Field_Character>
                    <name>Band Number</name>
                    <field_number>1</field_number>
                    <field_location unit="byte">1</field_location>
                    <data_type>ASCII_Integer</data_type>
                    <field_length unit="byte">3</field_length>
                </Field_Character>
                <Field_Character>
                    <name>Center Wavelength</name>
                    <field_number>2</field_number>
                    <field_location unit="byte">5</field_location>
                    <data_type>ASCII_Integer</data_type>
                    <field_length unit="byte">4</field_length>
                    <unit>nm</unit>
                </Field_Character>
            </Record_Character>
        </Table_Character>
    </File_Area_Ancillary>
</Product_Ancillary>
```


9.2 *UVVS Cube*

(TBD)

9.3 *EET*


```
<?xml version="1.0" encoding="UTF-8"?>
<?xml-model href="http://pds.nasa.gov/pds4/pds/v1/PDS4_PDS_1700.sch"
schematypens="http://purl.oclc.org/dsdl/schematron"?>

<Product_Observational xmlns="http://pds.nasa.gov/pds4/pds/v1"
    xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
    xsi:schemaLocation="http://pds.nasa.gov/pds4/pds/v1
http://pds.nasa.gov/pds4/pds/v1/PDS4_PDS_1700.xsd">
    <Identification_Area>

<logical_identifier>urn:nasa:pds:izenberg_pdart14_meap:data_eetable:ele_evt_8hr_orbit_201
2-2013</logical_identifier>
        <version_id>1.0</version_id>
        <title>Mercury Energetic Electrons Events Table</title>
        <information_model_version>1.7.0.0</information_model_version>
        <product_class>Product_Observational</product_class>
        <Modification_History>
            <Modification_Detail>
                <modification_date>2016-04-12</modification_date>
                <version_id>1.0</version_id>
                <description>Izenberg PDART 2014 MEAP Energetic Electron Events
Table</description>
            </Modification_Detail>
        </Modification_History>
    </Identification_Area>
    <Observation_Area>
        <Time_Coordinates>
            <start_date_time>2012-04-21Z</start_date_time>
            <stop_date_time>2013-12-26Z</stop_date_time>
        </Time_Coordinates>
        <Primary_Result_Summary>
            <purpose>Science</purpose>
            <processing_level>Derived</processing_level>
            <description>Data from the MESSENGER Neutron Spectrometer (NS) have been used
to detect
              and characterize energetic electron (EE) events within Mercury's
magnetosphere.</description>
```

```
        </Primary_Result_Summary>
        <Investigation_Area>
            <name>MESSENGER</name>
            <type>Mission</type>
            <Internal_Reference>

<lid_reference>urn:nasa:pds:context:investigation:mission.messenger</lid_reference>
                <reference_type>data_to_investigation</reference_type>
            </Internal_Reference>
        </Investigation_Area>
        <Observing_System>
            <name>MESSENGER NS</name>
            <Observing_System_Component>
                <name>MESSENGER</name>
                <type>Spacecraft</type>
                <Internal_Reference>

<lid_reference>urn:nasa:pds:context:instrument_host:spacecraft.mess</lid_reference>
                    <reference_type>is_instrument_host</reference_type>
                </Internal_Reference>
            </Observing_System_Component>
            <Observing_System_Component>
                <name>NS</name>
                <type>Instrument</type>
                <Internal_Reference>

<lid_reference>urn:nasa:pds:context:instrument:ns.mess</lid_reference>
                    <reference_type>is_instrument</reference_type>
                </Internal_Reference>
            </Observing_System_Component>
        </Observing_System>
        <Target_Identification>
            <name>Mercury</name>
            <type>Planet</type>
            <Internal_Reference>
                <lid_reference>urn:nasa:pds:context:target:planet.mercury</lid_reference>
                <reference_type>collection_to_target</reference_type>
            </Internal_Reference>
        </Target_Identification>
    </Observation_Area>
    <Reference_List>
        <External_Reference>
            <doi>10.1126/science.1211141</doi>
            <reference_text>Ho et al., 2011, MESSENGER observations of transient bursts
of
               energetic electrons in Mercury's magnetosphere, Science, 333, 1865-8.
            </reference_text>
        </External_Reference>
    </Reference_List>
    <File_Area_Observational>
        <File>
            <file_name>ele_evt_8hr_orbit_2012-2013.tab</file_name>
            <creation_date_time>2016-03-16T13:20:13Z</creation_date_time>
            <file_size unit="byte">10879836</file_size>
        </File>
        <Header>
            <offset unit="byte">0</offset>
            <object_length unit="byte">354</object_length>
            <parsing_standard_id>7-Bit ASCII Text</parsing_standard_id>
            <description>The first row of the table contains column
headings.</description>
        </Header>
        <Table_Character>
            <name>Energetic Electron events, 8 hour orbit, 2012-2013</name>
            <offset unit="byte">354</offset>
            <records>30733</records>
            <record_delimiter>Carriage-Return Line-Feed</record_delimiter>
            <Record_Character>
                <fields>22</fields>
                <groups>0</groups>
                <record_length unit="byte">354</record_length>
```

```
                <Field_Character>
                    <name>Event Number</name>
                    <field_number>1</field_number>
                    <field_location unit="byte">1</field_location>
                    <data_type>ASCII_Real</data_type>
                    <field_length unit="byte">16</field_length>
                    <description>EE event number. The value is repeated for 'Event
                      Length' rows in the file.</description>
                </Field_Character>
                <Field_Character>
                    <name>Event Length</name>
                    <field_number>2</field_number>
                    <field_location unit="byte">17</field_location>
                    <data_type>ASCII_Real</data_type>
                    <field_length unit="byte">16</field_length>
                    <description>Number of 20-second accumulations.  The value is
repeated
                      for 'Event Length' rows in the file.</description>
                </Field_Character>
                <Field_Character>
                    <name>Day of Year</name>
                    <field_number>3</field_number>
                    <field_location unit="byte">33</field_location>
                    <data_type>ASCII_Real</data_type>
                    <field_length unit="byte">16</field_length>
                    <description>Day of year on which the 20-second accumulation
                      occurs.</description>
                </Field_Character>
                <Field_Character>
                    <name>Month</name>
                    <field_number>4</field_number>
                    <field_location unit="byte">49</field_location>
                    <data_type>ASCII_Real</data_type>
                    <field_length unit="byte">16</field_length>
                    <description>Month in which the 20-second accumulation
                      occurs.</description>
                </Field_Character>
                <Field_Character>
                    <name>Day</name>
                    <field_number>5</field_number>
                    <field_location unit="byte">65</field_location>
                    <data_type>ASCII_Real</data_type>
                    <field_length unit="byte">16</field_length>
                    <description>Day in the month in which the 20-second
                      accumulation occurs.</description>
                </Field_Character>
                <Field_Character>
                    <name>Year</name>
                    <field_number>6</field_number>
                    <field_location unit="byte">81</field_location>
                    <data_type>ASCII_Real</data_type>
                    <field_length unit="byte">16</field_length>
                    <description>Year in which the 20-second accumulation
                      occurs.</description>
                </Field_Character>
                <Field_Character>
                    <name>Hour</name>
                    <field_number>7</field_number>
                    <field_location unit="byte">97</field_location>
                    <data_type>ASCII_Real</data_type>
                    <field_length unit="byte">16</field_length>
                    <description>Hour within the day in which the 20-second
                      accumulation occurs.</description>
                </Field_Character>
                <Field_Character>
                    <name>Minute</name>
                    <field_number>8</field_number>
                    <field_location unit="byte">113</field_location>
                    <data_type>ASCII_Real</data_type>
                    <field_length unit="byte">16</field_length>
                    <description>Minute within the hour in which the 20-second
```

```
      accumulation occurs.</description>
</Field_Character>
<Field_Character>
    <name>Second</name>
    <field_number>9</field_number>
    <field_location unit="byte">129</field_location>
    <data_type>ASCII_Real</data_type>
    <field_length unit="byte">16</field_length>
    <description>Second within the minute in which the
      20-second accumulation occurs.</description>
</Field_Character>
<Field_Character>
    <name>MET</name>
    <field_number>10</field_number>
    <field_location unit="byte">145</field_location>
    <data_type>ASCII_Real</data_type>
    <field_length unit="byte">16</field_length>
    <unit>s</unit>
    <description>Mission elapsed time, and is the mission tag
      time in seconds of the start of the associated
      accumulated period.</description>
</Field_Character>
<Field_Character>
    <name>Orbit Number</name>
    <field_number>11</field_number>
    <field_location unit="byte">161</field_location>
    <data_type>ASCII_Real</data_type>
    <field_length unit="byte">16</field_length>
    <description>Unique identifier for a given orbit of
      MESSENGER around Mercury. Orbit number is defined as
      starting at apoherm and is calculated using the MET
      value and the appropriate SPICE kernels. Orbit
      numbering does not start until MESSENGER performs the
      Mercury orbit insertion. Until that time the value for
      orbit number is 0.</description>
</Field_Character>
<Field_Character>
    <name>Altitude</name>
    <field_number>12</field_number>
    <field_location unit="byte">177</field_location>
    <data_type>ASCII_Real</data_type>
    <field_length unit="byte">16</field_length>
    <unit>km</unit>
    <description>Spacecraft altitude above the subsatellite
      point on the target in units of km.</description>
</Field_Character>
<Field_Character>
    <name>Latitude</name>
    <field_number>13</field_number>
    <field_location unit="byte">193</field_location>
    <data_type>ASCII_Real</data_type>
    <field_length unit="byte">16</field_length>
    <unit>deg</unit>
    <description>Target-centric latitude of the spacecraft
      subsatellite point in degrees.</description>
</Field_Character>
<Field_Character>
    <name>Longitude</name>
    <field_number>14</field_number>
    <field_location unit="byte">209</field_location>
    <data_type>ASCII_Real</data_type>
    <field_length unit="byte">16</field_length>
    <unit>deg</unit>
    <description>Target-centric longitude of the spacecraft
      subsatellite point in degrees.</description>
</Field_Character>
<Field_Character>
    <name>Local Time</name>
    <field_number>15</field_number>
    <field_location unit="byte">225</field_location>
    <data_type>ASCII_Real</data_type>
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```
        <field_length unit="byte">16</field_length>
        <unit>hr</unit>
        <description>Local time of the spacecraft subsatellite
          point in hours from 0 to 24.</description>
    </Field_Character>
    <Field_Character>
        <name>Beta Angle</name>
        <field_number>16</field_number>
        <field_location unit="byte">241</field_location>
        <data_type>ASCII_Real</data_type>
        <field_length unit="byte">16</field_length>
        <unit>deg</unit>
        <description>Angle of the normal of the spacecraft
          orbital plane with respect to Mercury-to-Sun vector
          in degrees.</description>
    </Field_Character>
    <Field_Character>
        <name>Sun Distance</name>
        <field_number>17</field_number>
        <field_location unit="byte">257</field_location>
        <data_type>ASCII_Real</data_type>
        <field_length unit="byte">16</field_length>
        <unit>km</unit>
        <description>Distance of the spacecraft to the Sun in
          units of km.</description>
    </Field_Character>
    <Field_Character>
        <name>Periapsis Latitude</name>
        <field_number>18</field_number>
        <field_location unit="byte">273</field_location>
        <data_type>ASCII_Real</data_type>
        <field_length unit="byte">16</field_length>
        <unit>deg</unit>
        <description>Target-centric latitude of the spacecraft
          when it is at the periapsis (lowest) altitude for the
          given orbit number.</description>
    </Field_Character>
    <Field_Character>
        <name>Event Length Minute</name>
        <field_number>19</field_number>
        <field_location unit="byte">289</field_location>
        <data_type>ASCII_Real</data_type>
        <field_length unit="byte">16</field_length>
        <unit>min</unit>
        <description>Length of the EE event in minutes. The
          value is repeated for 'Event Length' rows in the file.
          </description>
    </Field_Character>
    <Field_Character>
        <name>SN</name>
        <field_number>20</field_number>
        <field_location unit="byte">305</field_location>
        <data_type>ASCII_Real</data_type>
        <field_length unit="byte">16</field_length>
        <unit>none</unit>
        <description>Event signal-to-noise, and is the measure
          of the size of the event within each 20-second
          accumulation.</description>
    </Field_Character>
    <Field_Character>
        <name>BP_TOT</name>
        <field_number>21</field_number>
        <field_location unit="byte">321</field_location>
        <data_type>ASCII_Real</data_type>
        <field_length unit="byte">16</field_length>
        <description>Total counts within the Borated Plastic
          sensor, 64-channel, 20-s spectral accumulation.</description>
    </Field_Character>
    <Field_Character>
        <name>BP_LOW</name>
        <field_number>22</field_number>
```

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                    <field_location unit="byte">337</field_location>
                    <data_type>ASCII_Real</data_type>
                    <field_length unit="byte">16</field_length>
                    <description>Total counts within the lowest 12 channels
                      of the Borated Plastic sensor, 64-channel, 20-s spectral
                      accumulation.</description>
                </Field_Character>
            </Record_Character>
        </Table_Character>
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</Product_Observational>
```

9.4 *TN Map*

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schematypens="http://purl.oclc.org/dsdl/schematron"?>
<?xml-model href="http://pds.nasa.gov/pds4/disp/v1/PDS4_DISP_1700.sch"
schematypens="http://purl.oclc.org/dsdl/schematron"?>
<?xml-model href="https://pds.nasa.gov/pds4/sp/v1/PDS4_SP_1100.sch"
schematypens="http://purl.oclc.org/dsdl/schematron"?>
<?xml-model href="http://pds.nasa.gov/pds4/cart/v1/PDS4_CART_1700.sch"
schematypens="http://purl.oclc.org/dsdl/schematron"?>

<Product_Observational xmlns="http://pds.nasa.gov/pds4/pds/v1"
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    xmlns:disp="http://pds.nasa.gov/pds4/disp/v1"
    xmlns:sp="http://pds.nasa.gov/pds4/sp/v1"
    xmlns:cart="http://pds.nasa.gov/pds4/cart/v1"
    xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
    xsi:schemaLocation="
    http://pds.nasa.gov/pds4/pds/v1 https://pds.nasa.gov/pds4/pds/v1/PDS4_PDS_1700.xsd
    http://pds.nasa.gov/pds4/disp/v1 https://pds.nasa.gov/pds4/disp/v1/PDS4_DISP_1700.xsd
    http://pds.nasa.gov/pds4/sp/v1 https://pds.nasa.gov/pds4/sp/v1/PDS4_SP_1100.xsd
    http://pds.nasa.gov/pds4/cart/v1
http://pds.nasa.gov/pds4/cart/v1/PDS4_CART_1700.xsd">
    <Identification_Area>

<logical_identifier>urn:nasa:pds:izenberg_pdart14_meap:data_tnmap:thermal_neutron_map</lo
gical_identifier>
        <version_id>1.0</version_id>
        <title>Mercury Thermal Neutron Map</title>
        <information_model_version>1.7.0.0</information_model_version>
        <product_class>Product_Observational</product_class>
        <Modification_History>
            <Modification_Detail>
                <modification_date>2017-02-09</modification_date>
                <version_id>1.0</version_id>
                <description>Peer reviewed version of the Izenberg PDART 2014 MEAP
Thermal Neutron Map Product</description>
            </Modification_Detail>
        </Modification_History>
    </Identification_Area>
    <Observation_Area>
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            <start_date_time>2004-08-13Z</start_date_time>
            <stop_date_time>2015-04-30Z</stop_date_time>
        </Time_Coordinates>
        <Primary_Result_Summary>
            <purpose>Science</purpose>
            <processing_level>Derived</processing_level>
            <description>MESSENGER Gamma-Ray Spectrometer (GRS) Anti-Coincidence Shield
(ACS) data
            have been used to map variations in thermal neutron absorbing elements across
            Mercury's surface.</description>
        </Primary_Result_Summary>
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            <type>Mission</type>
            <Internal_Reference>
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                <type>Spacecraft</type>
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                <type>Instrument</type>
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            <type>Planet</type>
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                </pds:Local_Internal_Reference>
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                    <disp:horizontal_display_direction>Left to
Right</disp:horizontal_display_direction>
                    <disp:vertical_display_axis>Line</disp:vertical_display_axis>
                    <disp:vertical_display_direction>Top to
Bottom</disp:vertical_display_direction>
                </disp:Display_Direction>
            </disp:Display_Settings>

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180.0</cart:west_bounding_coordinate>
                        <cart:east_bounding_coordinate
unit="deg">180.0</cart:east_bounding_coordinate>
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unit="deg">90.0</cart:north_bounding_coordinate>
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90.0</cart:south_bounding_coordinate>
                    </cart:Bounding_Coordinates>
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<cart:map_projection_name>Equirectangular</cart:map_projection_name>
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unit="deg">0.0</cart:latitude_of_projection_origin>
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Pair</cart:planar_coordinate_encoding_method>
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                                    <cart:pixel_resolution_x
unit="km/pixel">21</cart:pixel_resolution_x>
                                    <cart:pixel_resolution_y
unit="km/pixel">21</cart:pixel_resolution_y>
                                    <cart:pixel_scale_x
unit="pixel/deg">2</cart:pixel_scale_x>
                                    <cart:pixel_scale_y
unit="pixel/deg">2</cart:pixel_scale_y>
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                            </cart:Planar_Coordinate_Information>
                            <cart:Geo_Transformation>
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7560</cart:upperleft_corner_x>
                                <cart:upperleft_corner_y unit="km">-
3780</cart:upperleft_corner_y>
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                        <cart:Geodetic_Model>
                            <cart:latitude_type>planetocentric</cart:latitude_type>
                            <cart:spheroid_name>Mercury</cart:spheroid_name>
                            <cart:semi_major_radius
unit="km">2440.</cart:semi_major_radius>
                            <cart:semi_minor_radius
unit="km">2440.</cart:semi_minor_radius>
                            <cart:polar_radius unit="km">2440.</cart:polar_radius>
                            <cart:longitude_direction>Positive
East</cart:longitude_direction>
                        </cart:Geodetic_Model>
                    </cart:Horizontal_Coordinate_System_Definition>
                </cart:Spatial_Reference_Information>
            </cart:Cartography>

        </Discipline_Area>
    </Observation_Area>
    <Reference_List>
        <External_Reference>
            <doi>10.1016/j.icarus.2015.02.002</doi>
            <reference_text>Peplowski et al., 2015, Geochemical terranes of Mercury's
              northern hemisphere as revealed by MESSENGER neutron measurements, Icarus,
              253, 346-363.</reference_text>
        </External_Reference>
    </Reference_List>

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            <file_name>thermal_neutron_map.img</file_name>
            <creation_date_time>2016-03-18T17:32Z</creation_date_time>
            <file_size unit="byte">259200</file_size>
            <comment>Image file in standard PDS4 IMG format</comment>
        </File>
        <Array_2D_Image>
            <name>Mercury Thermal Neutron Map</name>
            <local_identifier>Image_Object</local_identifier>
            <offset unit="byte">0</offset>
            <axes>2</axes>
            <axis_index_order>Last Index Fastest</axis_index_order>
            <description>
                The file has 259200 elements, which correspond to a
                720 x 360 degree map (0.5 degree wide pixels in east
                longitude, latitude). The elements are arranged from
```

```
                the top (90 lat, -180 lon) across, then down (last
                entry is -90, 180). Each element is a byte. Pixel
                values range from 0 to 255; converting them to
                physical units (10^-4 cm2/g) requires multiplying the
                pixel value by 0.222860. Pixel values of zero are
                unmapped, and this corresponds to all latitudes less
                than (south of) 20 deg N.
            </description>
            <Element_Array>
                <data_type>UnsignedByte</data_type>
                <unit>10**-4 cm**2/g</unit>
                <scaling_factor>0.222860</scaling_factor>
                <value_offset>0</value_offset>
            </Element_Array>
            <Axis_Array>
                <axis_name>Line</axis_name>
                <elements>360</elements>
                <sequence_number>1</sequence_number>
            </Axis_Array>
            <Axis_Array>
                <axis_name>Sample</axis_name>
                <elements>720</elements>
                <sequence_number>2</sequence_number>
            </Axis_Array>
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    </File_Area_Observational>
    <File_Area_Observational_Supplemental>
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        </File>
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        </Encoded_Image>
    </File_Area_Observational_Supplemental>
</Product_Observational>
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9.5 *Enhanced GRS*

(TBD)