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FIPS EDR to CDR Conversion

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1 INTRODUCTION

This document explains the conversion of FIPS Experimental Data Records (EDR) to Calibrated Data Records (CDR). Refer to the EPPS CDR SIS and references therein for descriptions of FIPS and FIPS CDR data. Parameters related to instrument performance used below are described in more detail in the FIPS Calibration Report. This section is useful for understanding the FIPS conversions described below.

The concept of FIPS CDR data is simple: Map EDR data from the digital units (channels) stored in telemetry to physical units. More sophisticated processing is found in higher level data products, such as individual species phase space distributions, pitch-angle distributions, etc., which are beyond the scope of the CDR data. This philosophy allows more sophisticated data users to use the data in a nearly raw form, where only the largely unambiguous effects of measurement are removed. The PHA data product is an exception to this rule: Several additional pieces of information are added to these data to allow them to be used as independently as possible.

Where possible in these CDR products, counts are converted to physical units via division by the instrument accumulations performed during the measurement, and are referred to as differential flux. A good discussion of this of the related quantities of flux and intensity can be found in the section entitled 'Transfer Function' in the EPPS CDR SIS. Of note: The quantity "differential flux" described herein is analogous to the "differential intensity" quantity described in that section. The term "differential flux" is used here because it is commonly used the literature of the thermal plasmas and pick-up ions that are measured by FIPS. The user should also refer to given units and formulas to remove any remaining ambiguity.

2 BASIC QUANTITIES

A number of basic quantities used in the conversion of EDR to CDR data are derived from instrument ground calibration, or design parameters. Values for these quantities, or how to obtain them, are listed in this section.

2.1 Energy per charge, E/q

FIPS E/q tables are constructed by combining a table of possible E/q values with the particular stepping sequence in which FIPS was running during the measurement, and are given in units of keV/e. These values must be known *a priori* from tables uploaded to the EPPS flight software.

The E/q tables are included as ancillary data in the CDR archive. The latest E/q table dated before the EDR file date should be used for all conversions. Care must be taken to use the set of columns that correspond to the stepping table in use at the time of the measurement, as given in the 'mode' column of the data.

At every E/q step, ions from a finite band-pass window (δ) are accepted. For FIPS this window is 0.05.

2.2 *Accumulation time*

Accumulation time τ_i as a function of E/q step i is contained within the CDR E/q table and is looked up from there.

2.3 *Energy-geometric factor*

The energy-geometric factor, g = 8.31E-5 mm^2 (eV/eV), represents an effective collection area for the sensor, which includes the physical aperture area and the energy acceptance. The energy acceptance is essentially the E/q passband; the width around each E/q value. The E/q of an ion must fall within this passband to be measured by the FIPS sensor at the given E/q step. This factor does not include the solid angle of the collection area, which is considered separately in Section 2.5.

2.4 *X-Y to incident angle*

A Cartesian coordinate system is defined on the wedge-strip zig-zag anode associated with the start MCP (described in the EDR SIS). To translate these anode positions to incident angles, the following procedure is performed:

1) The (x,y) pair (in units of MCP pixel) is transformed to plane polar coordinates (r, θ_{MCP}) in the typical fashion to yield angles in the [0,360] range. Before conversion, constants offsets (X0,Y0) are subtracted from the (x,y) pair.

2) The polar pair (r, θ_{MCP}) is then transformed to incident zenith (θ) and azimuthal (ϕ) angle via the following equations:

$$\theta = R0 + R1r + R2r^2 + R3r^3 + R4r^4 + R5r^5$$

$$\phi = -360(P1(\frac{180}{\pi}))\theta_{MCP} + P0$$

Constants for the conversions are given below. Zenith angles outside of the interval of [15,75] degrees can result from uncertainty in the position measurement. These correspond to incident angles outside of the allowed field of view and should be discarded.

Flight Software Version	
v6	**All other versions**
X0 = 23.6017 Y1 = 27.1122	X0 = 31.5159 Y0 = 34.2993
N/A	P0 = 6.5 P1 = -1.0
R0 = -34.0497 R1 = 34.652 R2 = -9.70052 R3 = 1.43296 R4 = 0.100514 R5 = 0.00274512	R0 = -18.5303 R1 = 10.1646 R2 = -0.565382 R3 = 0.0164266 R4 = 0 R5 = 0

2.5 Viewing solid angle

The viewing solid angle ($\Delta\Omega$) represents the range angles, in both angular dimensions, over which particles are collected. FIPS field of view (FOV) covers a 1.4π steradian solid angle, a portion of which is obstructed by the MESSENGER spacecraft and sunshade. The unobstructed FOV area, 1.15π steradian, is used for rate-based calculations described in this document. Each (x,y) pixel views a particular solid angle area, varying by approximately 30% across the MCP. These values are given in the ancillary file, FIPA_FYYYYDDDCDR_V#.txt, and used as part of the weighting factor in CDR PHA words (described below).

2.6 Detection Efficiency and Noise Removal

Detection efficiencies for FIPS depend on mass, energy and incident angles. These have been determined from ground [*Zurbuchen et al.*, 2004] and in-flight calibration (described elsewhere). Prior to assigning efficiencies, CDR counts have been noise filtered [*Gershman et al.*, 2013] and assigned to specific masses according to the E/q-TOF track in which they fall [*Raines et al.*, 2013].

3 METHODS

3.1 PHA

Time of flight (TOF) in digital units is converted to nanoseconds via the factor 666 ns / 1024 channels in all but the raw PHA. For raw PHA, in which the TOF contains the full 11 bits measured, 666 ns / 2048 channels is used.

Energy per charge (E/q, in keV/e) is found by lookup in the E/q stepping table file.

Incident zenith and azimuthal angles are calculated from (x,y) positions on the FIPS Start anode from relations as described in section 2.4.

The weighting factor is composed of the per pixel solid angle; efficiency as a function of mass, energy and time; particle velocity; decimation (if any), and instrument step accumulation time. PHA words that have been filtered out for one or more reasons (below) have a weighting factor of 0.0:

- Measured on obstructed region of detector
- Poor quality measurement (heavy ions only -- see quality flags)
- Noise filtering (heavy ions only)

3.2 Rate spectra to differential flux spectra

FIPS rates are converted to differential flux ($dJ/\mathrm{d}E$) in units of $(\mathrm{keV/e})^{-1}\ \mathrm{sec}^{-1}\ \mathrm{cm}^{-2}\ \mathrm{sr}^{-1}$, by dividing out all of the instrument accumulations via the following formula:

$$\left(\frac{dJ}{dE}\right)_i = \frac{C_i}{(E/q)_i \tau_i g \eta_i \Delta\Omega}$$

Counts (C_i) are taken directly from the EDR data at ESA voltage step i. The energy per charge (E/q, in keV/e) at step i can be found in the corresponding E/q table. See section 2.1

for details. The accumulation time (τ_i, in seconds) is the time over which particles are collected in step i, found by look up in the E/q table. The energy-geometric factor (g, in mm^{-2} (eV/eV)) is taken from section 2.3. Efficiencies (η_i) for protons are used since they dominate the rate spectra in almost all cases. Since rate spectra lack angle information, the full 1.15π sr solid angle ($\Delta\Omega$) is used, effectively averaging the flux over the entire FOV.

The differential flux can be easily converted to phase space density (s^3/m^6) using the following equation, where v_i and m are in SI units (m/s and kg, resp.):

$$\left(\frac{dJ}{dE}\right)_i = 1.6022 \times 10^{-20}\left(\frac{v_i^2}{m}\right) f_i$$

Phase space densities computed from the rate spectra are implicitly averaged over the entire FOV. The use of PHA data is required to obtain three-dimensional phase space densities.

3.3 Velocity Distribution

For the CDR data, FIPS velocity distributions are given as normalized velocity distributions, rather than differential intensity. Mass-dependent efficiencies involved in the measurement process make this calculation much more sensible after counts have been attributed to specific ions, a process which is well beyond the scope of this data. The resulting probabilities ($P_{x,y}$) are unitless and calculated via the following formula:

$$P_{x,y} = \frac{C_{x,y}}{\sum_{x,y} C_{x,y}}$$

Counts ($C_{x,y}$) are taken directly from the EDR data in bin (x,y).

An estimate of the differential intensity for a particular incident angle can be calculated by the product of $P_{x,y}$ times the sum over E/q of the proton differential intensities, at the same time step. The incident angle is calculated from x,y position as described in section 2.4.

4 APPLICABLE DOCUMENTS

The following documents may be referenced for further details:

1. Zurbuchen et al. (The Fast Ion Plasma Spectrometer (FIPS) calibration report, MESSENGER Project report, 2004)
2. Andrews et al. (The Energetic Particle and Plasma Spectrometer Instrument on the MESSENGER Spacecraft, Space Science Reviews Volume 131, Numbers 1-4, August 2007)
3. Raines et al. (Distribution and compositional variations of plasma ions in Mercury's space environment: The first three Mercury years of MESSENGER observations, Journal of Geophysical Research, 118, p1604-1619, 2013)
4. Gershman et al. (Post-processing modeling and removal of background noise in space-based time-of-flight sensors, Deep Blue, 2013, http://hdl.handle.net/2027.42/100358)

5. Raines et al. (MESSENGER observations of the plasma environment near Mercury, Planetary and Space Science 59, p2004-2015, 2011)

5 REVISION HISTORY

Rev	Date	Author(s)	Description
	15Jul2009	Jim Raines	Initial version.
A	30Jul2009	Jim Raines	Revised description of flux and clarified wording.
B	02Dec2009	Jim Raines	Overhaul after initial PDS review.
C	15Jan2010	Jim Raines	Adjust data velocity distribution data product and rate to flux conversion.
D	30Aug2011	Jim Raines	Corrected error in differential intensity formula
E	01Jul2014	Jim Raines and the FIPS team	Updated after CDR product revision and redelivery.
F	11Dec2015	Jim Raines and the FIPS team	Clarified language surrounding “differential flux” quantity.