LEND CSETN CIRCULAR AND ELLIPTICAL ORBITAL DATA PROCESSING. J. G. Bodnarik[1], I. G. Mitrofanov[2], W. V. Boynton[1], D. K. Hamara[1], K. Harshman[1], A. S. Gardner[1], G. Chin[3], T. P. McClanahan[3], R. D. Starr[4], L. G. Evans[5], A. Sanin[2], M. Litvak[2], T. Livengood[3,6], [1]Lunar and Planetary Laboratory, Univ. of Arizona, Tucson, 1629 E. Univ. Blvd., AZ 85721-0091, (bodnarik@lpl.arizona.edu), [2]Institute for Space Research, RAS, Moscow 117997, Russia, Astrochemistry Laboratory, [3]NASA Goddard Space Flight Center, Greenbelt, MD, [4]Dept. of Physics, Catholic University of America, 620 Michigan Ave., N.E., Washington, DC, [5]Science Programs, Computer Science Corporation, Lanham, MD, [6]Dept. of Astronomy, University of Maryland, College Park, MD.

Introduction: Since July 2009, the Lunar Exploration Neutron Detector (LEND) [1, 2] aboard the Lunar Reconnaissance Orbiter (LRO) [3] has mapped the neutron flux from the Moon. LEND is outfitted with four types of neutron detectors: thermal and epithermal neutron omnidirectional sensors, a pair of thermal neutron Doppler filter sensors, four epithermal neutron collimated sensors, and a high energy neutron sensor. The data reduction procedures that reduce the raw elliptical orbit collimated epithermal neutron data into corrected higher-level derived data products are presented.

Background: The task of converting LEND raw neutron data into higher-level products has been transferred from the Institute for Space Research [4] to the University of Arizona. New data reduction algorithms have been designed and applied to the collimated sensor of epithermal neutrons (CSETN) data, during the circular orbit time period from September 15, 2009 through December 11, 2011 [5]. The raw data are corrected for Solar Energetic Particle (SEP) events, outlier or off-limit events, off nadir measurements, instrument warm-up, cosmic-ray variation, spacecraft altitude, and three sources of background counts for the collimated detectors: through the walls of the collimator, lunar neutrons scattered off the spacecraft into the detector, and cosmic rays interacting directly with the spacecraft.

Methods: The data reduction procedures presented in this work have been applied to the current set of data from September 15, 2009 through November 6, 2013 that will soon be released to the scientific community.

Solar Energetic Particle events. The LEND neutron sensors are sensitive to SEP events and are monitored to remove any data associated with these events. We exclude the entire UTC days' worth of LEND data, in which the SEP event onset and ending occurs, and assign a value of -1 for all records that occur in a SEP time interval.

Off-limit or outlier events. Infrequent and randomly distributed 'outlier' count rate values, produced by instrument memory corruptions or high voltage counter circuit micro-discharges, are present in the raw detector data. Detector outlier events are identified by statistically unlikely flux measurements greater than 11, as determined from a Gaussian histogram of the counts, and are assigned count rate values of -1 when converting to a derived record.

Off nadir measurements. Targeted observations for other LRO instruments sometimes require pointing away from nadir. A value of -1 is assigned to the count rate for nadir angles greater than 1^o.

Instrument warm-up correction. LEND sensors are power-cycled bi-weekly, requiring corrections for detector efficiency variations. Valid on-intervals are defined as at least 7 days long, excluding data from the first 6 hours after turn-on. Records that fall outside valid intervals are not converted to derived records.
Warm-up curves are generated for each detector for each 'on' interval and are fit to an exponential with fitted parameters representing the characteristic warm-up period,the start of the warm-up, and the asymtptote of the warm-up correction, $A_{i,j}$. Fits are weighted by the reciprocal square of the standard error of the mean for each orbital average.

Cosmic-ray variation correction. The galactic cosmic ray flux is modulated by the solar cycle, anti-correlated with the overall solar activity level. Lunar neutron emission is directly proportional to the cosmic ray flux, so LEND data must be normalized to this variation. Because there was little change in the cosmic-ray flux during the first 3 months of the mission, as indicated by the small variation in the $A_{i,j}$ values, the values for each detector were averaged over this period to generate long-term normalization values, A_1^o, A_2^o, A_3^o and A_4^o. All subsequent data were normalized by the ratio of the current $A_{i,j}$ value to its A_i^o value, since the subsequent $A_{i,j}$ values showed a gradual decrease over time due to the lower cosmic-ray flux as solar activity increased. Recorded counts (those not signaled by value -1) are converted directly to count rate, since the interval of LEND measurements is 1-second accumulation time. Count rates are sufficiently low that no dead-time correction is necessary. When a detector is turned off or has generated an outlier event, the average adjusted count rate for the "on" detectors is assigned to the "off" detector with an adjustment made for difference in efficiency based on their A_i^o ratios.

The final adjusted count rate is the sum of the adjusted rate for all four of the detector elements that are incorporated in the CSETN detector system.

The data have been adjusted for changes in efficiency and for long-term cosmic-ray flux changes, but still need to be corrected for short-term (tens of hours) changes in the cosmic-ray flux. We take the residual of the fit to the warm-up data as a means to correct for the short-term variations in neutron flux by making another fit to the orbital averages, but this time on the combined count-rate data for all 4 detectors to improve statistics. We generate smoothed curves as a 24-hour moving average of the residuals and this short-term cosmic-ray correction factor (CRCF) is evaluated at each raw record's collection time and the complete equation for the corrected count rate is determined.

Count rate uncertainties. The relative uncertainty on the corrected counts for any record is significantly greater when one or more of the sensors is not producing valid data. To create maps, it is necessary to calculate an average count rate of multiple records for a given lunar location. Thus it is necessary to properly weight the data in calculating the average, e.g. a record for which 4 detectors return data must be given more weight than a record or which only 2 or 3 detectors return valid records.

The data is weighted by the reciprocal of the variance, however estimating the variance with a low number of counts is not clear-cut. In general, one can assume that the variance in the number of counts recorded is the number of counts. Such an assumption is a reasonably good approximation to the true variance of the counts when one is dealing with a large number of counts. However, it is important to note that the number of counts only yields a best estimate of the variance, s^2, which is not necessarily equal to the true variance, σ^2. For example, a record with 2 counts and another record with 4 counts are both common occurrences, but the record with 2 counts would be given twice as much weight if the variance were taken as the number of counts. This type of weighting yields a systematically low result.

Since low counting rates are present in the LEND records, we need to have a better way to estimate the variance. Therefore, the value of the exponential efficiency function is used. This function is fit over a few hundred thousand records in each power 'on' cycle and is better estimate of the true variance at the time the data were collected.

The sum of the counts due to all detectors is adjusted when one or more detectors is off and the sum of the counts due to all four detectors is calculated.

Altitude Corrections. On December 15, 2011, the LRO spacecraft orbit changed from circular to elliptical with the periapsis near the South Pole. The orbital altitude then went from a nominal ~50 km in the circular orbit to ~ 30 km x 200 km in the elliptical orbit, causing an observed decrease in the count rate in the North relative to that in the South. To correct for the change in the average count rates in the CSETN detectors due to the altitude variations, an altitude correction was applied as the orbital averages were calculated and the altitude correction was applied again as the derived data records were generated. The adjustment was applied for altitudes greater than 59 km and less than 194 km. No correction is needed for values below an altitude of 59 km and values are ignored for altitudes at and above 194 km, but the latitude, longitude, record value, and time of each record is recorded for each ignored value.

References: [1] Mitrofanov I. G. et al. (2010a) *Space Sci. Rev.*, 150, 183-207. [2] Mitrofanov I. G. et al. (2010b) *Science*, 330, 483-486. [3] Chin, G. et al. (2007) *Space Sci. Rev. XXVII*, 129, 391-419. [4] Litvak M. L. (2012) *J. Geophys. Res.-Planets*, 117, 18. [5] Boynton W. V. et al. (2012) *J. Geophys. Res.-Planets*, 117, 19.