# Reduction of Mars Odyssey Neutron Data

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**Neutron Detection:** Energetic neutrons are produced in the atmosphere and regolith of Mars by galactic cosmic rays via spallation reactions. High energy neutrons are fast neutrons which loose their energy by both nonelastic interactions and elastic collisions with nuclei near the surface. Epithermal neutrons have energies lower than the threshold for inelastic scattering for major elements found in Martian surface materials. Thermal neutrons experience a lot of energy-exchange collisions to reach an equilibrium state with the surrounding materials.

The Los Alamos built neutron spectrometer onboard Mars Odyssey uses boron-loaded plastic scintillators to detect and separately measure thermal-, epithermal-, and fast-neutrons originating from Mars [1,2]. The spectrometer consists of a block of boron-loaded plastic that is diagonally segmented into four optically decoupled prisms that are read out by separate photomultiplier tubes. P1 is covered by cadmium foil, which absorbs neutrons below roughly 0.5 eV.

Thermal- and epithermal-neutrons are detected via the $^{10}B(n,\alpha)^{7}Li^{*}$ reaction, which produces a distinct peak in the pulse height spectrum at 93 keV electron equivalent light output due to the recoil of the reaction products. For each prism, the net count rate for this peak is determined from the Category 1 pulse height spectrum, which is a spectrum of single-interaction events.

Fast neutrons are separately measured by the detection of a characteristic, double pulse. The light output caused by proton recoils produced by the prompt interaction of a fast neutron and the hydrogen in the plastic provides a measure of the energy of the incident neutron. A second pulse of light corresponding to the absorption of the neutron at low energy by $^{10}B$, follows a delay in which the neutron is slowing down in the plastic, but does not produce light. This double-pulse signature occurs for neutrons above approximately 700 keV.

**Reduction Scheme:** Counting rates are acquired every 19.75 sec. During this interval, the spacecraft traverses ~1° of arc length. The reduction process is a series of corrections to be applied in a precise order to obtained maps of thermal, epithermal, and fast neutrons counting rates.

*Exclusion of anomalous data:* There are numerous occurrences when the data are not useful for science analysis: Solar Energetic Events (SEP) which were identified for approximately 180 days between Feb. 2002 and Dec. 2006, spacecraft being pointed off Nadir, engineering time, and single upsets. About 14% of the data set is discarded, and no attempt has been made to recover these data.

*Category 1 processing:* The objective is to extract the signal from the pulse height spectrum under the peak at 93 keV. The spectrum is first corrected for Analog-to-Digital Converter non-linearity, and then for gain and offset. This allows us to track the gain drift of each prism, and eventually to adjust the high voltage levels. The integration of the peak area for prism 1 (looking nadir) yields the epithermal counting rate, for prism 2 (looking forward) minus prism 4 (looking backward) the thermal counting rate, and for prism 3 (looking toward the spacecraft) the spacecraft background.

*Event mode:* A fast neutron counting rate is readily measured from the recoil (n,p) interaction in prism 1. However, after-pulsing (photomultiplier tube emits a characteristic "after pulse" caused by the production of secondary electrons through the impact of back-streaming ions on the photocathode) is removed by raising the lower level threshold.

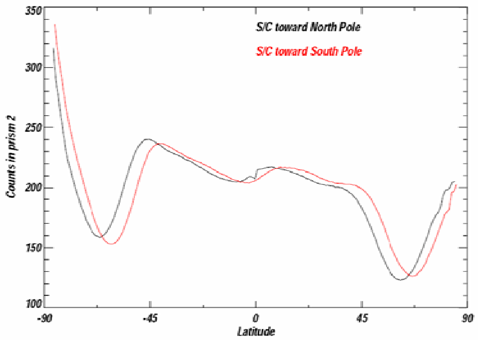

**Fig. 1:** Longitude-average count rates in prism 2 when the spacecraft is moving northward or southward.

*Background:* As measured during cruise [2], there is no significant background for thermal and epithermal counting rates. The background for fast neutrons is ~0.12 counts/sec.

*Height Correction:* The spacecraft altitude varies from 385 km to 455 km. A solid-angle law is used to account for this bias. At this point, no limb darkening is included to account for the non-Lambertian nature of the neutron emission.

*Latitude Aberration:* The detected neutron velocity measured in the spacecraft frame yields registration aberrations. By comparing data over the same region when the spacecraft is moving toward the North pole or the South pole, we have determined a latitude offset (Figure 1): Prism 1 which is looking toward the planet must be registered 0.59° ahead of the spacecraft nadir, prism 2 which is looking forward should be offset by 2.46° also ahead of nadir, prism 4 which is looking backward should be offset by 1.43° in the opposite direction of the spacecraft motion.

**Fig. 2:** Cosmic ray proxy as derived from epithermal neutrons as a function of time.

*Cosmic rays:* Because of solar cycle magnetic modulation, the flux of cosmic rays on Mars has varied by > 30% since Jan. 2002. The Odyssey neutron instrument returns an overload channel (energy > 2.5 MeV) that cannot be used since it depends highly on gain variations. Instead, we use the variations of prism 1 counting rate over all-longitudes within a ±30°-latitude average bellyband as a function of time. Since the mean water content of this region is less than 10%, counting rates are independent of atmospheric pressure (see next paragraph) and we assume the signal (depending solely on H content) to be constant. Thus we obtain a cosmic ray approximation useful to normalize the data (Figure 2).

*Atmospheric Pressure:* Neutron fluxes at the spacecraft depend on the $CO_2$ column density, which varies from 5 to 30 $g/cm^2$ because of local topography and seasonal variations. We use $CO_2$ pressure as predicted by the GCM code from F. Forget to model with MCNPX, a correction factor to normalize the measurements at 16 g/cm2 of $CO_2$ atmosphere (Figure 3). The correction does not apply to thermal neutrons because they do not depend significantly on pressure. They all depend on the ground water content. Therefore an iterative process has been implemented.

*Absolution Calibration:* For epithermal and thermal neutrons, we start from the γ 2.2 MeV line poleward of 85° as a function of $L_s$ [2,3]. We check for the growing thickness of seasonal $CO_2$ frost, and compare with the Ames GCM prediction at both poles. We model with thick $CO_2$ and normalize the maximal value. This process has been done, at the North and South poles independently, during their respective winters, and similar results have been obtained. For the fast neutrons, we monitor count rates as a function of time. A the South pole, counting rates flattens in winter, where it is predicted to be thick $CO_2$, which provides an absolute calibration for the fast neutrons.

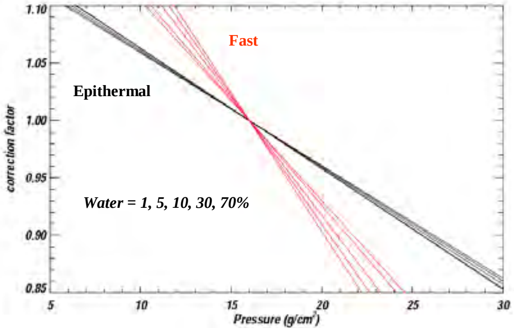

**Fig. 3:** Correction factor for pressure variations as a function of water content for epithermal and fast neutrons.

**Final data set:** At the end of the process, we obtain time series data for thermal, epithermal and fast absolute counting rate at the spacecraft. Errors are found to be better than ±10%. Time series data are then registered on 0.5° x 0.5° pixels. Such maps are smoothed to 2° (epithermal neutrons) and 4° FWHM (fast, thermal neutrons) to increase signal-to-noise. This smoothed window is smaller than the data spatial resolution. The mapping process is applied to frost-free data only.

**Conclusion:** The data reduction of the Los Alamos built instrument onboard Odyssey is now finished. Processed data are ready for science interpretation. To check the reliability of this data reduction, the processing has been done independently by T. Prettyman and S. Maurice. For the whole planet, the difference for thermal neutrons is better than ±1.6%, for epithermal neutrons better than ±2.6%, for fast neutrons better than ±7%. Within ±70° latitude, the difference between the outputs of the two codes is less than 1%.

**References:** [1] Boynton et al. (2004) *Space Sci. Rev*., 110, 37. [2] Feldman et al. (2002) *J. Geosphys. Res*., 1007, 1083. [3] Prettyman et al. (2004) *J. Geophys. Res.*, 109.