OBSERVATIONS OF NEUTRON ENVIRONMENT AT THE SURFACE AND IN ORBIT OF MARS. L. M. Martinez Sierra[1], I. Jun[1], C. Tate[2], J.E. Moersch[2], A.C. Martin[2], The MSL DAN Team, and The MSL RAD team, [1]**Jet Propulsion Laboratory/California Institute of Technology, Pasadena, CA, USA,** [2]University of Tennessee, Knoxville, TN, USA.

Introduction: The Dynamic Albedo Neutron (DAN) instrument on the Mars Science Laboratory (MSL) rover Curiosity has been making measurements since landing in August 2012 [1]. DAN measures thermal (E <0.4 eV) and epithermal neutrons (0.4 eV < E < ~1 keV) while operating in two different modes: active and passive. The active mode uses a pulsed neutron generator (PNG) to study the geological characteristics of the subsurface. In the passive mode, DAN measures the background neutron environment [1,2]. In addition to the MSL DAN, there are two other radiation-measuring instruments concurrently operating at Mars: MSL Radiation Assessment Detector (RAD) and Mars Odyssey High Energy Neutron Detector (HEND).

RAD is also part of the suite of instruments onboard MSL, designed to characterize the dose exposures due to charged particles, gamma rays, and neutrons on the surface of Mars. The instrument uses solid state detectors, an organic scintillator, and a plastic scintillator to measure broad-spectrum of energetic particle radiation. Particularly, RAD can detect 5 MeV and above neutrons [3].

HEND instrument is composed of 5 different detectors, each with different neutrons sensitivity and efficiency. HEND detects a wide range of neutron energies (0.4 eV <E< 10 MeV). By setting a threshold on the neutron counts, HEND is also able to differentiate when solar energetic particles (SEPs) reach Mars by flagging the data when solar activity is high [4].

Here, we briefly describe a long-term variation of the DAN passive data (especially thermal neutrons) collected through Sol 1300, complemented by the RAD (surface) and HEND (orbit) data.

There are two types of space radiation that can affect all of these three instruments: galactic cosmic rays (GCR) and SEP. Both types of particles are energetic enough to pass through the atmosphere and penetrate to the Martian subsurface. The GCR and SEP naturally react with the materials in the atmosphere and Mars surface and generate the secondary neutrons environment. There is also another source of neutrons for DAN – neutrons from the Multi Mission Radioisotope Thermoelectric Generator (MMRTG) that supplies power, and at the same time produces neutrons from the ^{238}Pu decay [2].

A previous study by Jun et al. [2] has shown that the DAN passive data are more strongly dependent on change of composition of surface material than change of radiation environment. Also, it was shown that the DAN passive data are dominated by the contribution from MMRTG neutrons. These two facts make the use of DAN passive data to estimate the true natural neutron environment difficult.

This work contributes to the outgoing attempt on exploring a possibility of using the DAN passive data (mainly thermal neutron counts) to improve our understanding of the neutron background environment at the surface of Mars, but this time using the RAD/HEND data to complement the DAN data.

Methodology: First, to qualitatively investigate how the DAN raw passive data would be sensitive to changes in the ambient environment, we compared the DAN thermal data (on surface) with the HEND data onboard Mars Odyssey (in orbit). HEND is designed to measure neutrons from the surface of Mars. Nevertheless, it is also sensitive to secondary radiation generated inside the spacecraft when GCR and SEP particles interact with the materials and components from the structure. The HEND data set is provided in counts for the 5 different detectors. In the folowing analys the >1 MeV neutron counts from the large detector (LD) and the scintillator (ScHi) were used for the comparison. In addition, to complement this qualitative analysis, the DAN/HEND data were compared with the RAD penatrating counter data [5].

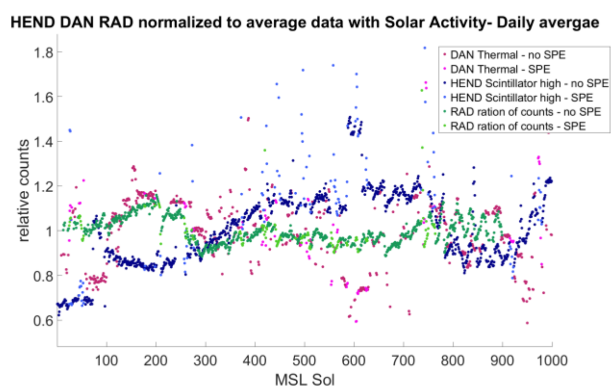

Figure 1. Normalized sol average neutron and charge particle measurements on Mars using the data from the DAN, HEND, and RAD instruments. The RAD data used are up to sol 900 while the DAN/HEND data are up to sol 1300. Only the data up to sol 1000 are shown in this plot.

From these comparisons, we would want to gain an insight of possible correlations between the neutron environments seen from orbit and detected on the surface to bring some light on the propagation methods of space radiation through the atmosphere. Figure 1 presents the sol average data for each instrument, normalized to their mean count rate when there is no solar activity. Although there are some possible correlations on the data at some time periods, a long-term trend is not clearly recognized. Some of the noticeable observations among the three data sets are:

- Anti-correlation of HEND/DAN between sol 110-250.
- Zig-zag behavior of both RAD/HEND data between sol 770-910.
- The RAD data begin with higher counts, then decrease with time and increase again while the HEND data generally show an opposite variation.
- The DAN data show little variation from the mean counts at several sol locations (e.g., between sol 230-270 at a single location known as "John Klein") while there are larger variations during other intervals (e.g., between sol 340-580 while performing a rapid traverse route).

A special focus was given to the data obtained during high solar activity because the count enhancement for both RAD and HEND due to the changes of ambient environment would be more evident. Figure 1 clearly shows peaks in the HEND data during SEP events. At the same time, only a handful of these events were seen by RAD, leading to the conclusion that not all solar proton events were penetrating or energetic enough to reach the surface. The same conclusion has been discussed by Hassler et al. [6] using RAD data for the first 300 sols. Besides, it is also consistent with the lack of observable enhancements on DAN passive counts during SEP events.

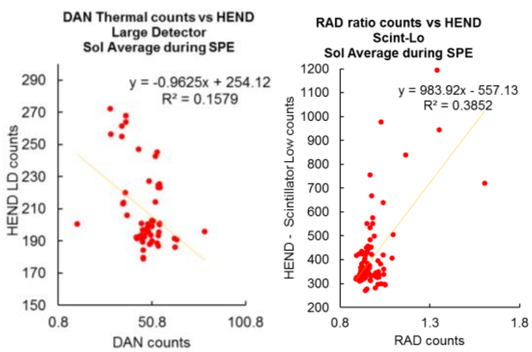

Figure 2 a) the left plot shows a scatter plot between the DAN thermal counts and the HEND counts on the large detector; **b)** the right plot shows a scatter plot between the RAD counts and the HEND low-scintillator counts. Here two different HEND channels were chosen that present the closest correlation of the data. The linear trend equations are shown in the plot to emphasize the poor correlation between the two data sets.

Figure 2 compares the data using two scatter plots between HEND and DAN and HEND and RAD. By filtering the data only during solar active periods, it is thought that the plots would show possible correlations of the DAN/HEND and RAD/HEND. However, the DAN and HEND data show an "anticorrelation" with no strong linear dependence. It was expected that the RAD and HEND data are more directly proportional because of their sensitivity to the SEP, however Figure 2b indicates that the relationship between the data is not as strong as anticipated.

Preliminary Interpretation: Comparisons of the DAN/HEND/RAD data were done with the objective of identifying potential signs that can relate neutron count enhancements between on orbit and at the surface of Mars during the same periods. So far there is no clear direct relationship that can be extracted from this initial study even during high solar activity intervals. The lack of any direct correlation can be partially explained by the fact that the DAN passive data vary strongly with regolith composition. Neutrons from the MMRTG are also dominating the DAN neutron counts, making it difficult to compare the DAN surface data directly to orbital measurements. Another reason for the weak correlation may be that the spatial coverage of HEND is different from that of the MSL instruments (DAN and RAD). While DAN and RAD are investigating the environment within the localized Gale Crater, the spatial footprint of HEND is very large (an order of 600 km in diameter).

Future Work: Our current study implies that if we want to use the DAN data to understand the long-term variation of neutron environment at the surface of Mars, we will have to distinguish the space radiation-generated neutrons from those by MMRTG. For this, we will perform extensive simulations using various solar proton spectra as sources to characterize intensities and their energies passing through the atmosphere and reaching the surface. At the same time the long term trend in Figure 1 show possible diurnal, seasonal, and atmospheric changes, which also require further investigation.

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