Measuring Neutrons and Gamma Rays on Mars - The Mars Science Laboratory Radiation Assessment Detector MSL/RAD

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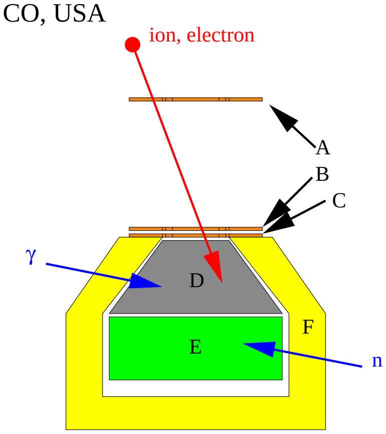

Figure 1: The RAD instrument concept. Charged particles are measured with the multiple $\mathrm{d}E/\mathrm{d}x$ vs. total E method, whereas neutrals (gammas and neutrons) are measured in detectors D and E only.

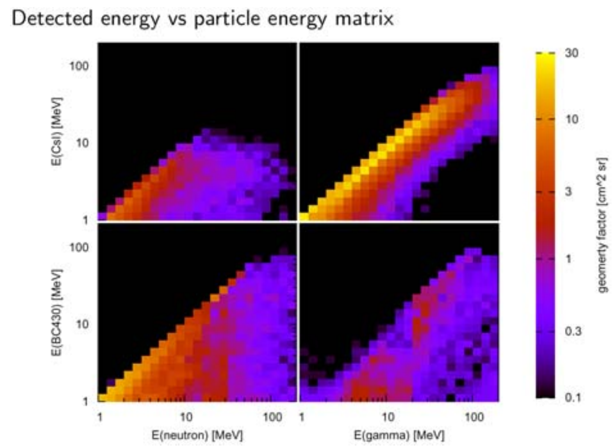

Figure 2: Instrument response functions of MSL/RADs CsI(Tl) (top panels) and BC-432m (bottom panels) detectors to neutrons (left-hand panels) and gamma rays (right-hand panels).

Introduction

The Mars Science Laboratory (MSL) missions Radiation Assessment Detector (RAD) will measure the radiation environment on the Martian surface. One of the difficult measurements is that of the neutral radiation component consisting of neutrons and gamma rays. Different from Earth, this neutral component contributes substantially to the total dose on the planetary surface, principally because the Martian atmosphere is so thin.

The RAD instrument is capable of measuring neutral particles through a combination of sensitive anti-coincidence and organic and anorganic scintillator materials. Figure 1 shows a schematic view of RAD and explains its basic functions. In this work, we will explain how RAD will measure the neutral particle radiation on Mars and compare with calibration results.

Background

The problem of inverting measured neutron and gamma data is a non-trivial task. For all inversions, one generally assumes that the measurement process can be described by a system of linear equations. In fact, these follow from a Fredholm equation which can be discretized into a set of linear equations, $\mathbf{A}\vec{f} = \vec{z}$, where the matrix $\mathbf{A}$ describes the instrument response function (IRF), $\vec{f}$ the underlying, but unknown, “real” physical parameters, and $\vec{z}$ the measured data. The inversion of this deceiptfully simple-looking set of equations is in fact a key example of an ill-posed or inverse problem. Such problems are notoriously difficult to solve. Based on previous work [1, 2] we are currently developing inversion schemes for RAD data based on various techniques (see Kharytonov et al. [2]). Key to any sucessful inversion scheme is accurate knowledge of the instrument response function.

Instrument Response Function

Figure 2 shows the istrument response function of MSL/RAD’s CsI(Tl) and BC-432m (plastic) detectors to neutrons and gamma rays. The IRF was simulated with the CERN-package GEANT in which relevant processes can be included. The upper half of the figure shows the CsI(Tl) response, the bottom half the plastic (BC-432m) response. The left-hand panels show the reponses to neutrons while the right-hand panels show the responses to gamma rays. The response of CsI(Tl) for gamma rays (top right panel) is close to diagonal and in stark contrast to the CsI(Tl) response to neutrons. The reason for the difference lies in the detailed physics of the interactions of gamma rays and neutrons with CsI(Tl). The bottom two panels show the responses for RAD's plastic scintillator to neutrons (left) and gamma rays (right). Here, the left-hand panel is "better" than the right-hand one, again because of the different physics of the neutron and gamma-ray interactions with this proton-rich scintillator.

Given the measurements, $\vec{z}$, and the IRF, $\mathbf{A}$, we can invert $\vec{z}$ to obtain the neutral-particle spectra, $\vec{f}$. A similar analysis has been applied to data from the interplanetary SOHO/EPHIN and STEREO/SEPT instruments [1].

Quenching

The light yield of charged particles in scintillators is not strictly proportional to the deposited energy, but shows quenching. This reduces the light output in a non-linear fashion modeled by [3] as

$$\frac{\mathrm{d}L}{\mathrm{d}x} = \frac{S(\mathrm{d}E/\mathrm{d}x)}{1 + k\frac{\mathrm{d}E}{\mathrm{d}x}} \quad \text{or} \quad = \frac{S(\mathrm{d}E/\mathrm{d}x)}{1 + k\frac{\mathrm{d}E}{\mathrm{d}x} + C\left(\frac{\mathrm{d}E}{\mathrm{d}x}\right)^2}, \qquad (1)$$

where $\mathrm{d}L/\mathrm{d}x$ is the fluorescence light energy emitted per unit path lengh, $\mathrm{d}E/\mathrm{d}x$ is the specific energy loss for the charge particle (ionization density), $S = 1.0$ the scintillation efficiency, and $k = 1.29 \cdot 10^{-2}$ g cm^{-2} MeV^{-1} the fraction of ionized and excited molecules along the particle track which do not radiatively deexcite (i.e., do not produce scintillation). In the more complicated second-order expression, $C = 9.59 \cdot 10^{-6}$ g^{2}2 cm^{-4} MeV^{-2} takes into account various modes and degrees of excitation in the scintillator. We included this quenching effect in the simulations of the IRF using the parameters given above (from [4]). Quenching is included at every step. The resulting simulated data are in good agreement with calibration measurements (not shown here).

Calibration data

RAD was calibrated at the neutron facility of the Physikalisch-Technische Bundesanstalt (PTB) in Braunschweig in spring 2008. Figure 3 shows RAD pulse height spectra (in RED) for 19MeV neutrons which entered RAD from the zenith direction. The lower x-axis shows the light output whereas the upper x axis shows the corresponding quenched energy values in MeV. The green curve shows the instrument response derived from forward model using a combination of the GEANT4 Monte-Carlo code for RAD, a numerical integration of eq. 1 (simple version using $k = 1.3$), and an additional Gaussian noise term. The area shaded in light red shows the range for which the model has been fitted to the data to obtain the noise width.

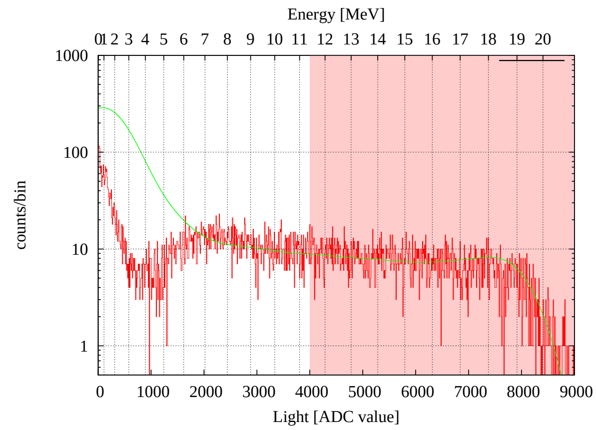

Figure 3: Neutron calibration data. Red shows pulse-height data, green instrument model response.

Summary, Conclusions, and Outlook

We have investigated methods to invert neutral particle data acquired with MSL's RAD instrument and compared them with calibration data. While the agreement is good for neutrons from a calibration beam in a forward model, as shown in the previous section, more work will be required for omnidirectional neutrons with unknown spectral properties using the inversion technique. We expect an asymmetry in fluxes from soil and sky for neutrons. Preliminary simulation results show a different behavior for gamma rays. Therefore, models of the IRF are likely to require additional inputs about the radiation environement.

Acknowledgements This work was supported by the German Space Agency, DLR, under grant 50 QM 0501.

References

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