MARTIAN NEUTRON ENERGY SPECTROMETER (MANES). R. H. Maurer[1], D. R. Roth[1], J. D. Kinnison[1], J. O. Goldsten[1], R. Fainchtein[1], and G. Badhwar[2], [1]Johns Hopkins University Applied Physics Laboratory, 11100 Johns Hopkins Road, Laurel, MD 20723, richard.maurer@jhuapl.edu, [2]Johnson Space Center, Houston, TX 77058.

Introduction: High energy charged particles of extragalactic, galactic and solar origin collide with spacecraft structures and planetary atmospheres. These primaries create a number of secondary particles inside the structures or on the surfaces of planets to produce a significant radiation environment. This radiation is a threat to long term inhabitants and travelers for interplanetary missions and produces an increased risk of carcinogenesis, central nervous system (CNS) and DNA damage. Charged partcles are readily detected; but, neutrons, being electrically neutral, are much more difficult to monitor. These secondary neutrons are reported to contribute 30-60% of the dose equivalent in the Shuttle and MIR station (1).

The Martian atmosphere has an areal density of 37 g/cm^2 primarily of carbon dioxide molecules. This shallow atmosphere presents fewer mean free paths to the bombarding cosmic rays and solar particles. The secondary neutrons present at the surface of Mars will have undergone fewer generations of collisions and have higher energies than at sea level on Earth. Albedo neutrons produced by collsions with the Martian surface material will also contribute to the radiation environment.

The increased threat of radiation damage to humans on Mars occurs when neutrons of higher mean energy traverse the thin, dry Martian atmosphere and encounter water in the astronaut's body. Water, being hydrogeneous, efficiently moderates the high energy neutrons thereby slowing them as they penetrate deeply into the body. Consequently, greater radiation doses can be deposited in or near critical organs such as the liver or spleen than is the case on Earth. A second significant threat is the possibility of a high energy heavy ion or neutron causing a DNA double strand break in a single strike.

MANES Instrument Objectives: MANES was proposed in response to AO 99-HEDS-01for additional payloads to fly on the Mars 2003 Lander. The proposal was submitted in August 1999 and was selected for the definition phase in November 1999.

The MANES instrument is partitioned into two channels-—the Low Energy Spectrometer (LES) and the High Energy Spectrometer (HES)—which are mounted to a central housing containing the electronics to operate the instrument and provide the spacecraft interface. It will have a mass of 5 kg and measure the Martian neutron spectrum over a large energy range. Specific objectives for MANES are

1) measure the neutron fluence energy spectrum on the surface of Mars over an energy range from 100 keV to 50 MeV with a goal of 20 keV to 100 MeV;
2) monitor both the diurnal and solar cycle time variations in the neutron environment;
3) compare the measured neutron spectra to models that propagate the incident cosmic ray spectrum through the Martian atmosphere and calculate the reflected albedo from the Martian surface;
4) determine the neutron directionality ratio;
5) measure the fluence ratios of protons to alphas to heavy ion groups in the HES anti-coincidence shield for the incident charged particles;
6) from the results, calculate the dose, dose rate, dose equivalent and dose equivalent rate to be expected by astronauts on Mars.

MANES Instrument Design: The LES uses a helium 3 gas tube to measure neutrons in the energy range from 100 keV or less to about 5 MeV. Two of these tubes will be flown with some polyethylene absorber to help determine differences between the propagated and reflected neutron spectra (directionality). The tubes will operate in both the common ^{3}He(n,p)^{3}H neutron absorption reaction mode and in the elastic neutron scattering mode that monitors the ^{3}He recoil. The absorption reaction has an energy release of Q=0.764 MeV which is added to the incident neutron energy. The spectrum has peaks corresponding to the most prominent neutron energies plus the Q of the reaction. If a thermal neutron peak is present as at sea level on Earth, it will provide a continuous energy calibration. Modeling and beam facility testing will provide necessary corrections for tube efficiency and the elastic scattering transfer function.

The HES will consist of a pair of 5-7 mm thick, 3 cm^2 lithium drifted silicon detectors ganged together to maximize the number of targets or fractions of a mean free path presented to the natural neutron beam. Charged silicon recoil nuclei, nuclear fragments, protons and alphas are progeny of the neutron-silicon collisions in the detector and their ionization depositions are collected and measured by standard pulse height techniques. Both elastic and inelastic reactions contribute to the total solid state detector efficiency. A thick detector offers increased efficiency which is important as the neutron energy increases to tens of MeV.

The silicon detectors will be surrounded by a CsI cup and plug scintillators that will serve to veto charged particle depositions in the silicon. In addition to using the CsI as an anti-coincidence shield, we will record the light in the CsI with PIN photodiodes to yield information on charged particle ion groups. The plug or puck will face the Martian surface and also be able to record information on the most prominent gamma rays emitted from the soil. Rise time discrimination methodology will be used to distinguish the different types of radiation.

Results: Engineering prototype gas tube and silicon solid state detectors have been tested and evaluated since 1998 under funding from the National Space Biomedical Research Institute (NSBRI) through NASA Cooperative Agreement NCC 9-58. Testing of detectors has been carried out with Cf, PuBe and AmBe radioactive neutron decay/spallation sources and with mono-energetic neutron beams. The Columbia University Radiological Research Accelerator Facility (RARAF) supplied mono-energetic neutrons between the energies of 0.5 and 20 MeV by the use of p-t, d-d and d-t reactions. RARAF is an NIH supported resource center through grants RR-11623 (NCRR) and CA-37967 (NCI).

The ^{3}He gas tube detector has consistently shown the classic responses to both radioactive and beam neutrons. Wall effect, epithermal, recoil and absorption count peaks are readily resolved in the pulse height spectra. For example, for 2.46 MeV neutrons the ^{3}He(n,n)^{3}He elastic recoil reaction produces short rise time pulses while the ^{3}He(n,p)^{3}H absorption/capture reaction produces long rise time pulses. Pulse rise time is used to discriminate between the two effects. The full width at half maximum of the epithermal peak is about 25 KeV and indicative of the LES detector energy resolution. The greater width of the neutron absorption peak is due mainly to the energy spread of the incident neutron beam. Data plots will be presented on these results.

The 5mm thick lithium drifted silicon solid state detector has been evaluated using mono-energetic neutron beams at RARAF. Since the cross section for the neutron capture rection in the gas tube falls precipitously above 1-2 MeV, a more dense detector medium must be used for the higher neutron energies. Neutron energies of 5.9, 14, 16.25 and 18.5 MeV were used to determine the overall efficiency and deposited enrgy spectra. The spectra observed over this energy range show considerable structure since we are in a region where nuclear resonances are prominent. The lowest energy deposition events give a smooth response and are due to the elastic scatter of the incident neutrons from the silicon detector nuclei and extend from our low energy detector cutoff (250 KeV as determined by noise) to 0.133 times the incident neutron energy as determined by the kinematics of the silicon recoil nucleus in the elastic reaction. An intermediate energy deposition region with minor structure is due to the moderately sized recoil fragments in the inelastic collisions including resonance excitation and decay. An example of such a fragment is a magnesium nucleus produced in a neutron-silicon collision that also creates an alpha particle. The high energy end of the deposition spectrum contains significant structure in the form of peaks which have energies up to the incident neutron energy and are due to a superposition of various proton and alpha particle states. The different energies of these peaks are determined by the kinetic energy given the proton or alpha particle in the different inelastic collision excitation and decay states. Again data plots will be presented.

The efficiency of the silicon detector is governed by the total cross section for neutron-silicon reaction as a function of energy. The experimental efficiency for the 5mm thick detector in the neutron energy range of 5.9 to 18.5 MeV was determined to be 4-5%. We compared our experimental results with both NASA deterministic (2) and Dept. of Energy Monte Carlo (3) models and found very good agreement for efficiency. This agreement indicates that MANES can efficiently measure neutrons in the 5-20 MeV range. Since the models predict the efficiency to be greater than 3% out to neutron energies of 100-150 MeV, we expect our bulk silicon detector to be useful at these higher energies as well.

Modeling: We are using the CERN GEANT4 software suite (4) to model our experimental results and run virtual experiments on our detector configuration. The GEANT4 code uses the Evaluated Nuclear Data Files (ENDF) as input for all particle reactions. It tracks all products of reactions and conserves energy at each reaction point. We have reproduced both the experimental detector efficiency and high energy deposition events for our 18.5 MeV runs at RARAF and are in the process of completely simulating all our RARAF experiments. Our ultimate objective is to develop a complete transfer function for MANES to deduce the most probable incident neutron spectrum.

References:

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