DOSE SPECTRA FROM ENERGETIC PARTICLES AND NEUTRONS (DoSEN).

Sonya Smith[1], **Nathan Schwadron**[1]**. Chris Bancroft**[1], **Peter Bloser**[1], **Jason Legere**[1], **James Ryan**[1], **and Harlan Spence**[1], **Joe Mazur**[2], **Cary Zeitlin**[3]
[1]University of New Hampshire, 8 College Road, Durham NH, 03824, sonya.s@unh.edu, n.schwadron@unh.edu, [2]The Aerospace Corporation, Joseph.E.Mazur@aero.org, [3]Southwest Research Institute, Earth Oceans and Space Science Institute, University of New Hampshire, 8 College Road, Durham NH, 03824, zeitlin@boulder.swri.edu

Abstract. DoSEN is an early-stage space technology research project that combines two advanced complementary radiation detection concepts with fundamental advantages over traditional dosimetry. DoSEN not only measures the energy but also the charge distribution (including neutrons) of energetic particles that affect human (and robotic) health in a way not presently possible with current dosimeters. For heavy ions and protons, DoSEN provides a direct measurement of the Lineal Energy Transfer (LET) spectra behind shielding material. Linear energy transfer (or LET) is the mean energy absorbed locally, per unit path length, when a charged particle traverses material. An LET spectrometer measures the amount of energy deposited in a detector of some known thickness and material property as a high-energy particle passes through it, usually without stopping. For LET measurements, DoSEN contains stacks of thin-thick Si detectors similar in design to those used for the Cosmic Ray Telescope for the Effects of Radiation (CRaTER). CRaTER is the first instrument of its kind to provide the needed ground truth measurements of LET spectra that provide the direct and critically-needed link between biological effectiveness to the radiation environment. With LET spectra, we can now directly break down the observed spectrum of radiation into its constituent heavy ion components and through biologically-based quality factors provide not only doses and dose-rates, but also dose-equivalents, associated rates and even organ doses. DoSEN also measures neutrons from 10-100 MeV, which requires enough sensitive mass to fully absorb recoil particles that the neutrons produce. The penetrating nature of the neutrons is offset by their intensity and sufficiently long exposure times, thus the constraining envelope dimension is the range of the recoil particles—typically protons in hydrogenous material. Because it is prohibitive to make a detector large enough to absorb the full energy of each neutron, the response of the instrument is broad, but still the task of measuring the spectrum and intensity in the featureless neutron spectrum is straightforward. Such technology has been in use for decades, but adapting it to the smallest, most efficient and lowest mass envelope is challenging. DoSEN develops the new concept of combining these independent measurements, and using the coincidence of LET measurements and neutron detection to significantly reduce backgrounds in each measurement. The background suppression through use of coincidence allows for significant reductions in size, mass, and power needed to provide measurements of dose, neutron dose, dose-equivalents, LET spectra, and organ doses. Thus, we introduce the instrument concept and present first lab measurments from DoSEN, a promising low mass device that detects the full spectrum of energetic particles, heavy ions and neutrons to determine biological impact of radiation in space.

DoSEN is an Innovation for LET and Neutron Coincidence (Fig. 1) to provide complete characterization of radiation biological effectiveness in a small and light-weight device. Such a device must be capable of measurement of LET spectra and neutrons. We de-

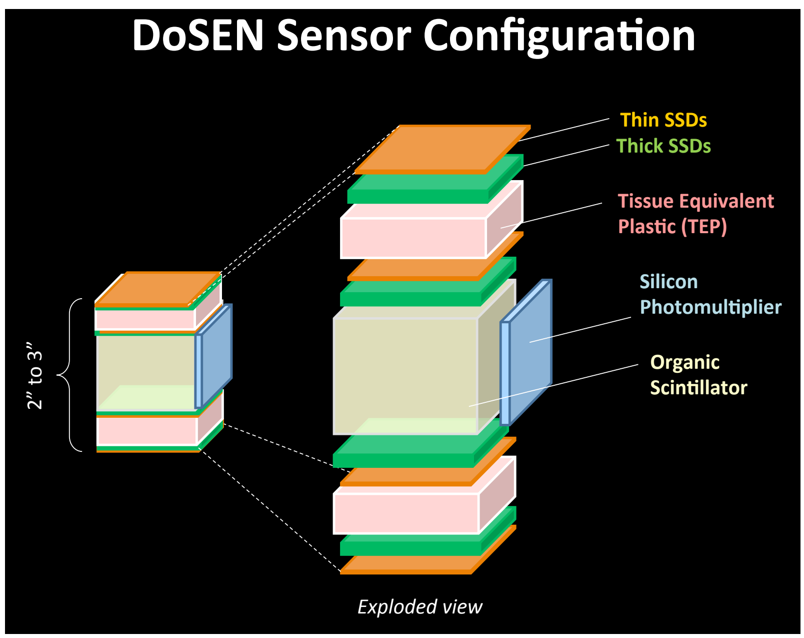

Figure 1. *The DoSEN sensor configuration includes a combination of Solid State Detectors (SSDs), organic scintillator with PSD and Si photomulitipliers (SiPMs) allowing coincident detection of energetic particle LET and neutrons. The unique coincidence offered by LET & neutron detection promises a significant advance for a new generation of dosimetry measurements.*

scribe here a new concept of ***combining*** these independent measurements, and using the coincidence of LET measurements and neutron detection to significantly reduce backgrounds in each measurement. The background suppression through use of coincidence allows for significant reductions in size, mass, and power needed to provide measurements of dose, neutron dose, dose-equivalents, LET spectra, and organ doses. The use of coincidence techniques has a long history in space physics. Often, the use of such techniques results in transformational shifts in research. For example, the use of triple coincidence in spectrometry led to measurements of ion composition within plasmas [e.g., 1] and on the Interstellar Boundary Explorer Mission [2] triple coincidence techniques are used to pick out a very weak signal of neutral atoms from many competing backgrounds [e.g., 3]. Without such coincidence measurements many of the *in situ* discoveries over the last two decades in space science would not have been possible. The CRaTER instrument itself combines a stack of six solid-state detectors (SSDs) with three sets of thin and thick SSDs separated by Tissue Equivalent Plastic [TEP; 4]. Coincidence provides not only suppression of backgrounds, but also separation between energetic particle sources from beyond the Moon and albedo sources from the Moon itself [5].

A similar transformational advance is provided by the DoSEN concept in which coincidence is achieved by combining a CRaTER-like LET measurements via a stack of four SSDs with neutron measurements using an organic scintillator with pulse-shape discrimination (PSD) coupled to Si Photomultipliers (SiPMs). The SiPM (also known as the solid-state photo-multiplier or the multi-pixel photon counter) operates like a Photomultiplier Tube (PMT); however with at least an order of magnitude less mass and volume. The SiPM is compact and low mass, and will eventually allow the SSDs to go on all six sides of the detector for full 3-D detection of sources. A SiPM is a novel photo-detector originally developed in Russia for high-energy physics applications [6-8]. It consists of a two-dimensional array of small cells, typically ~50 μm is size, each of which acts as an independent avalanche photo-diode. These cells are reversed-biased slightly above their breakdown voltage so that they operate in "limited Geiger mode:" when a photon is absorbed, an avalanche is quickly generated which produces a large signal independent of the number of photons that was absorbed. A resistor in series with the cell quenches the avalanche after several tens of ns. The outputs of all the cells are summed together into an analog sum so that the intensity of the incident light is proportional to the number of cells that absorb photons.

The advantages of the SiPM include high gain ($\sim 10^6$) at low operating voltages (typically 20-70 V), compactness, insensitivity to magnetic fields, fast timing response (rise times less than 1 ns), and the potential for low cost through mass production runs. SiPMs have by now been shown by many groups to perform well as readout devices for scintillators [e.g., 9-12].

In addition to introducing the DoSEN instrument, we show recent results from laboratory measurments including sensor calibration and gamma-ray coincidence measurements.

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