Fast neutron background characterization with the Radiological Multi-sensor Analysis Platform (RadMAP)

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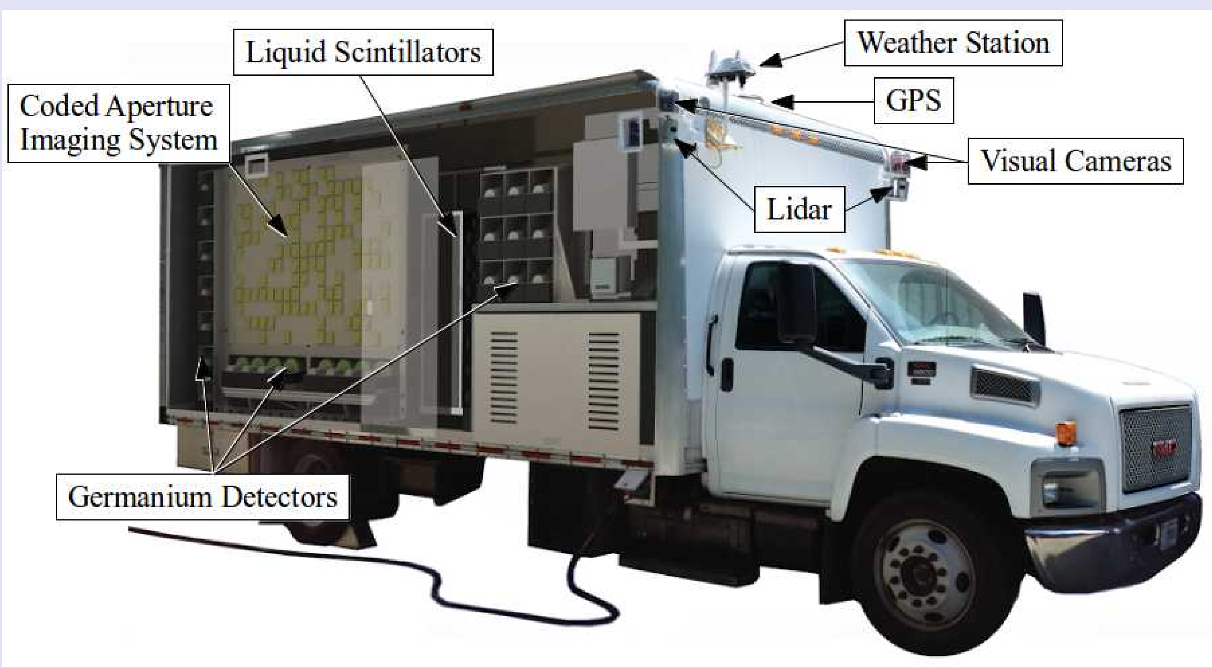
Introduction

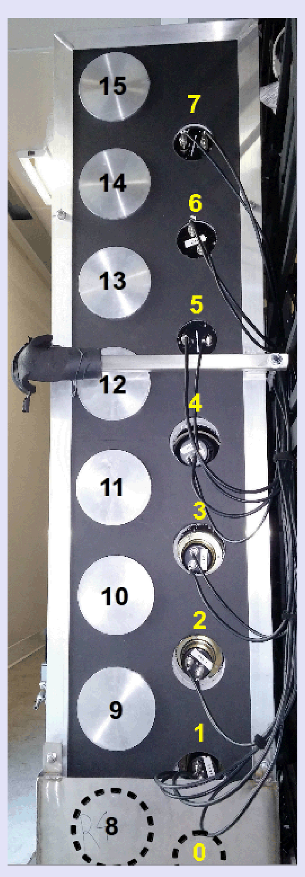
In an effort to characterize the fast neutron radiation background, 16 EJ-309 liquid scintillator cells were installed in the Radiological Multi-sensor Analysis Platform (RadMAP) to collect data in the San Francisco Bay Area. Each fast neutron event was associated with specific weather metrics (pressure, temperature, absolute humidity) and GPS coordinates. The expected exponential dependence of the fast neutron count rate on atmospheric pressure was demonstrated and event rates were subsequently adjusted given the measured pressure at the time of detection. Pressure-adjusted data was also used to investigate the influence of other environmental conditions on the neutron background rate. Using National Oceanic and Atmospheric Administration (NOAA) coastal area lidar data, an algorithm was implemented to approximate sky-view factors (the total fraction of visible sky in the hemisphere overhead) for points along RadMAP's route.

Experimental System

RadMAP, previously known as the Mobile Imaging and Spectroscopic Threat Identification (MISTI) system, was originally developed by the Naval Research Laboratory as a mobile gamma-ray source detection and localization platform. The platform is a General Motors 20 foot box truck with an on board generator to provide power to its detectors and sensors. LBNL began acquiring data with MISTI in the San Francisco Bay Area in November 2011. It was subsequently renamed RadMAP given its change of mission focus to background characterization and its additional suite of integrated sensors and detection capabilities. Following the transfer, the system was used for primarily for gamma-ray background characterization and source detection studies. RadMAP began collecting fast neutron background data in May 2012 following the installation of the liquid scintillator cells.



Radiological Multi-sensor Analysis Platform (RadMAP) with sensors and detection systems labeled

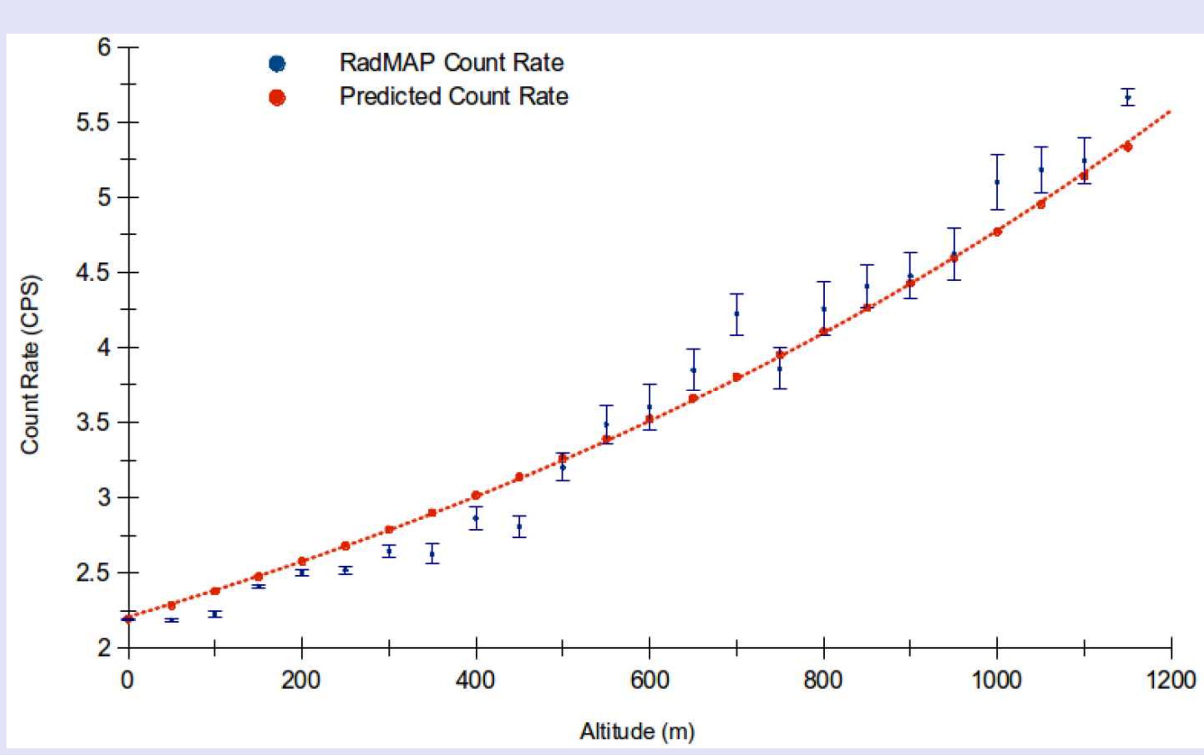


For this experiment, 16 EJ-309 organic liquid scintillator cells were installed in RadMAP. EJ-309 was used for its pulse shape discrimination (PSD) characteristics. The tail-to-total method was used for all PSD calculations in selecting neutron interactions in the detection medium. In RadMAP, each individual detector is oriented horizontally and stacked vertically in columns of eight detectors each as pictured and numbered in the figure. The total active detection volume of the system is approximately 25 L. Five inch Hamamatsu and Photonis photomultiplier tubes were coupled to the scintillator cells. Each identified neutron event was associated with specific weather metrics (pressure, temperature, absolute humidity) and GPS coordinates for subsequent count rate analysis.

Left: The 16 EJ-309 liquid scintillator detectors as viewed when facing the rear of the truck's cargo space. Detector channels 0 and 8 are located inside the leak containment safety structure.

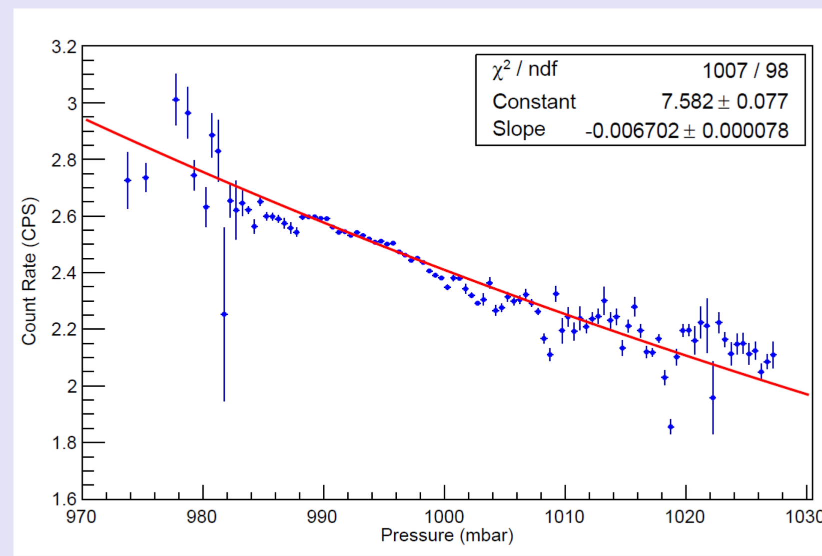
Altitude and Pressure Influence

The fast neutron background is produced primarily as a result of cosmic ray showers in the upper atmosphere. At altitudes below 15 km above the surface of the earth, an exponential decrease in the number of particles in the cosmic ray shower is observed due to attenuation. The 15 km point is commonly known as the Pfotzer point due to Georg Pfotzer's measurements and observations in the 1930's. RadMAP neutron data was compared to predictions from Pfotzer's measurements.

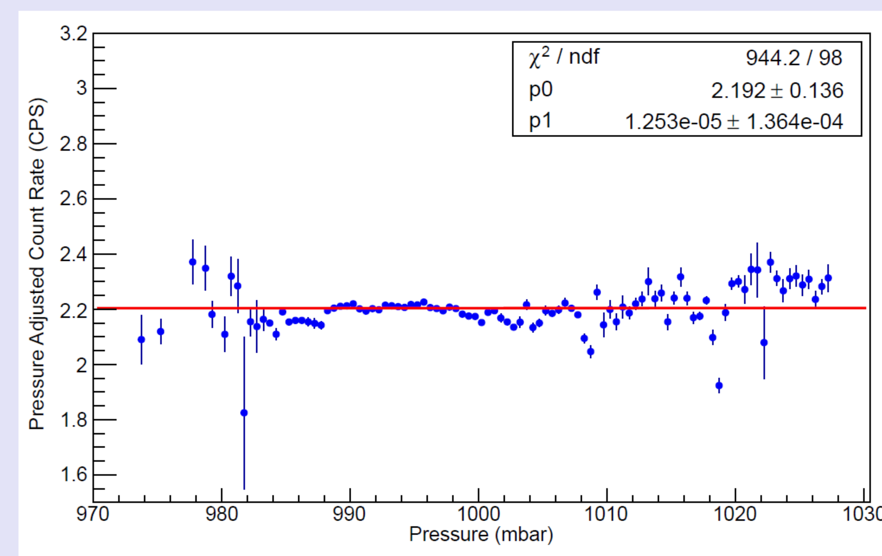


RadMAP mobile run observed and predicted neutron count rates. The predicted rates are relative to the sea level measured count rate.

Even at a constant altitude, a wide range of pressures may be observed within a few hours time. Given the significant variation in count rates due to changing atmospheric pressure, in order to investigate other factors influencing the neutron background the count rates are adjusted based on atmospheric pressure at the time of detection. The exponential fit parameters from the histogram containing pressure data for all datasets were used to determine the appropriate count adjustment. The next column shows the effect of applying the pressure adjustment to the data.

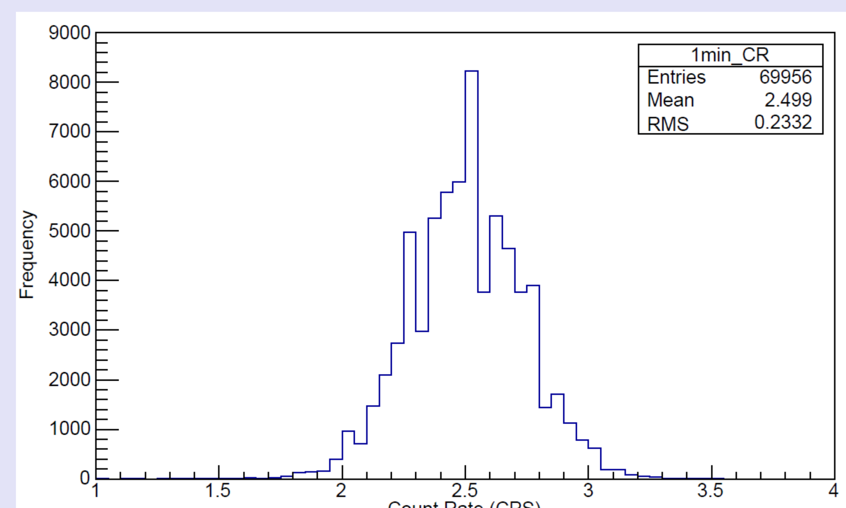


Atmospheric pressure data for all usable RadMAP runs (mobile and stationary)

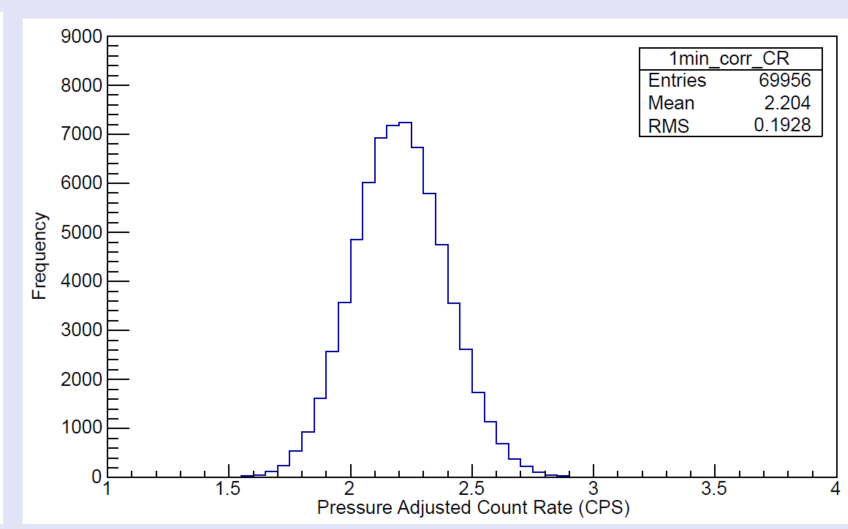


Pressure data after count rate adjustment is applied

For every run, count rates are determined for every minute of data acquisition and the rate is filled into a count rate frequency histogram. The result should be a Poisson distribution of observed rates centered about the mean value. By applying the pressure adjustment to this data, a reduction of 31% in the systematic error is obtained. This narrowing of the distribution increases the understanding of the expected count rate and will result in greater sensitivity and specificity in detection of a source over background.



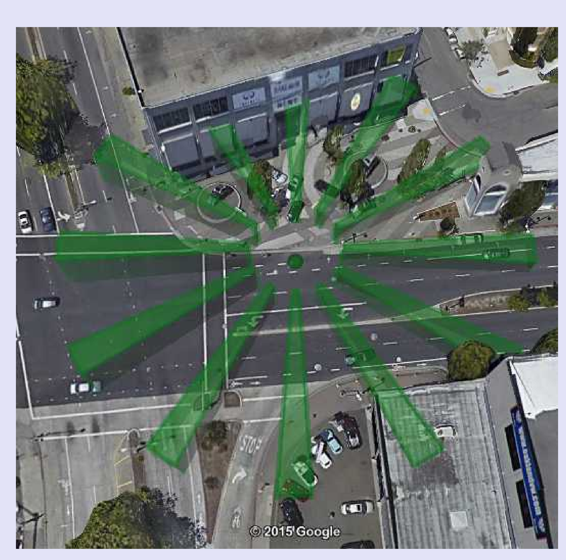
Unadjusted distribution of count rates for all RadMAP runs combined.



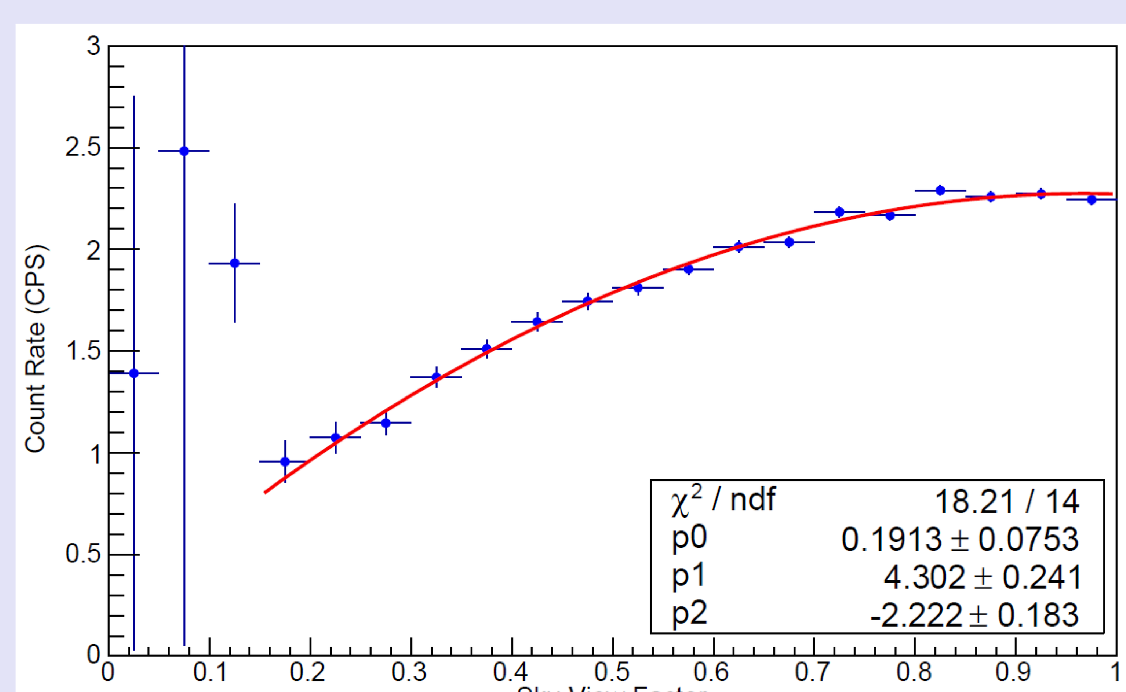
Pressure adjusted distribution of count rates for all RadMAP runs combined.

Surrounding Structures Influence

Using available National Oceanic and Atmospheric Administration (NOAA) coastal area lidar data, an algorithm was implemented to approximate sky-view factors (the total fraction of visible sky in the hemisphere overhead) for points along RadMAP's route. The intent of this study is to determine whether the presence of tall buildings has a shielding influence or if it results in a "ship effect" scenario where additional neutrons are produced. The algorithm searches for lidar points within 12 search windows around each point along the route. The maximum elevation and distance to that point within each window is then used to approximate the fraction of visible sky from the perspective of the detection system.



An example of the 12 search windows used to approximate the sky-view factor. The windows extend upward in altitude to capture all lidar points.



Pressure adjusted count rates for sky-view factors from all runs combined that travel through select portions of Berkeley, Downtown Oakland, or Downtown San Francisco.

Count rates were determined for sky-view factors from mobile data acquisition in Oakland, Berkeley, and Downtown San Francisco. Between the resulting pressure adjusted count rate of 2.25 CPS at a sky-view factor of 1 and a rate of 0.95 CPS at a sky-view factor of 0.2 a suppression of 58% in the rate was observed. The suppression at low sky-view factors is the greatest residual effect (after pressure adjustment) studied and represents a significant influence on the neutron background count rate.

Conclusions

These fast neutron background characterization studies both complement and enhance ongoing and previously conducted research in this field. Data exhibited good agreement with observations originally made by Pfotzer on background event rate at various altitudes. Pressure adjustments effectively reduce systematic error contributions to the overall background count rate distribution and allow for the study of other environmental influences. Results also extend current research on the suppression of the fast neutron count rate in urban areas. This study employed the novel method of using lidar data and the calculation of the sky-view factor to characterize the magnitude of background suppression. This project provides a comprehensive characterization of the fast neutron background and employs methods that may be applied to various detection scenarios and systems, both mobile and stationary.

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