Interplanetary Radiation Harnessing Voltaic System

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Introduction

Cosmic rays were first discovered in 1912, consisting of mostly protons (about 89%), alpha particles (10%) and even some heavier nuclei (less than 1%). The cosmic ray energy outside of earth's atmosphere is comparable to other deep space energies. The average cosmic ray energy density is about 1 eV/cm^3 in interstellar space, which is comparable the galactic magnetic field energy density: ~0.25 eV/cm^3, and the cosmic microwave background (CMB) radiation energy density: 0.25 eV/cm^3. A more noticeable source of particle radiation energy is solar wind. The composition of solar wind is a mixture of ionized hydrogen, 8% alpha particles, and trace amounts of heavy ions and atomic nuclei. At 1 astronomical unit (AU) from the Sun, typical solar wind densities is on the order of 8 protons/cm^{-3}, with average flow speed of 440 km/s and temperature of 1.2×10^5 K. These high energies and charges of primary cosmic ray particles affect astronauts during space travel. A report by Zeitlin et al. on the measurements of the particle radiation energy inside the spacecraft by the Radiation Assessment Detector during its journey to Mars confirms the hazards posed by these radiations, compromising general safety.

This data indicates that the cosmic rays outside of earth's atmosphere can be used via the kinetic energy of the ray particles in generating electricity with a muon-voltaic system as a viable means of propulsion.This poster describes a project to produce such a voltaic system. We have taken the data terrestrially, so it is not representative of the system efficiency in outer space. We will use gamma-radiation energy data to make predictions about the viability of such a system in outer space.

Methods

The goal of this project is to create a prototype a system that harness energetic interplanetary radiation for electric energy. The process of conversion from kinetic energy of the energetic particles takes place in the NaI scintillator. When the high energy ionizing radiation strikes the NaI block, the scintillation plastic exhibits luminescence. The system efficiency is compromised by quenching effects, which decreases the fluorescent effects of the NaI significantly. The overall signal production efficiency of the detector, however, also depends on the quantum efficiency of the PMT (typically ~30% at peak), and on the efficiency of light transmission and collection. Typical numbers are (for electrons): ≈40 photons/keV for NaI. The typical cosmic alpha particle's energy is on the order of 5 MeV. We expect the scintillation output to be proportional to the particular energy, since the light output of the scintillator is proportional to the energy of the incident radiation. To convert the photons generated by the scintillator into current, we are using a standard silicon solar panel, with 6V maximum output. This is then connected to a microcontroller for data logging via the circuit shown on the left (Fig. 1). With the necessary soldering to an Adafruit Data Logging shield the microcontroller has 3 analog inputs from the solar panel, charger, and battery. A standard lithium ion battery is connected to the last analog input.

Another possible design is to replace the solar panel with a germanium detector. One advantage of germanium is that it needs less energy (on average) to create an electron-hole pair, and thus has a higher efficiency output with better resolution. Secondly, while silicon-based detectors cannot be thicker than a few millimeters, germanium can have a depleted, sensitive thickness of centimeters, therefore it can be used as a total absorption detector, up to a few MeV. However, in a high solar-wind environment, the germanium tends to deplete and break, being rendered useless. This is not the case with plastic scintillation detectors, and that's why we go forward with the scintillation design in our prototype.

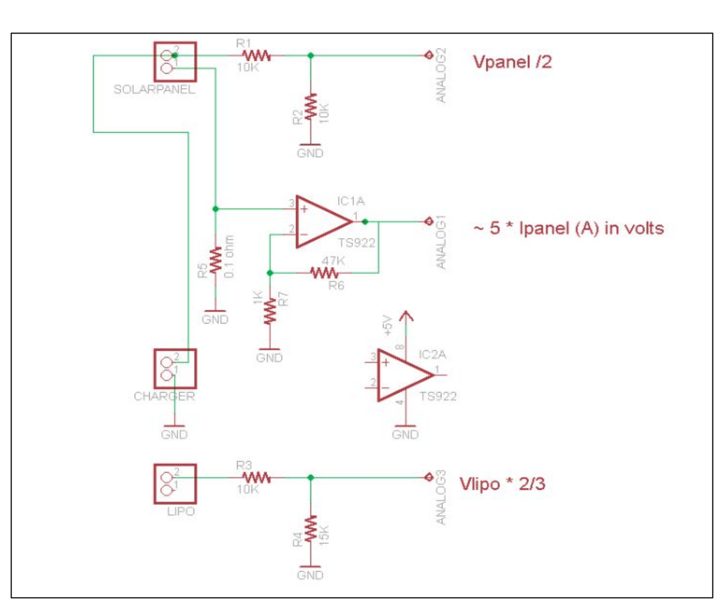

Figure 2: Schematic setup

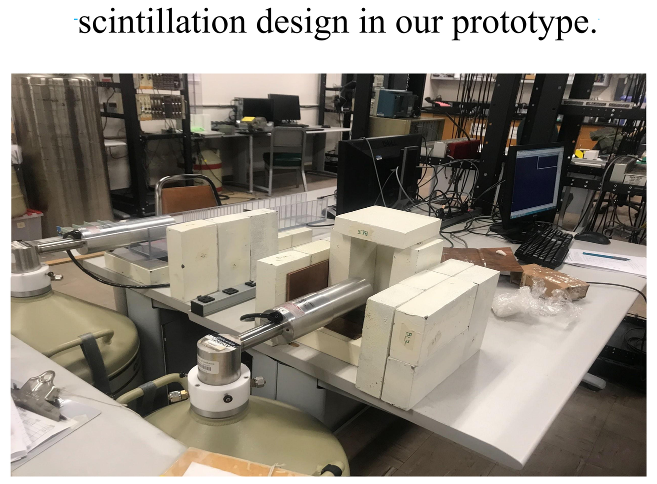

Figure 1: Experimental setup
(Details in Experiment)

Experiment

To test our hypothesis of using photon energy to drive a circuit and ultimately store it, we sampled data using a radiation source. Based on practicality and financial feasibility, our design utilized a gamma source. The experimentation took place in the basement of Etcheverry Hall at UC Berkeley.

We conducted the experiment using s TC 248 Amplifier, with coarse control at 11, and fine tuning at 0.5 ± 0.01. The applied voltage was 2500V. We used a variety of gamma sources to calibrate the detector, namely Am 241, Cs 137, Co 60, and Th 228. **Figure 3** shows the relative energy output of 8192 channels. We the radiation was incident on the NaI material for 10 minutes. The result obtained showed that the average output energy of scintillation photons is 3 eV, with an incident rate of 40,000 photons/MeV.

Data Analysis

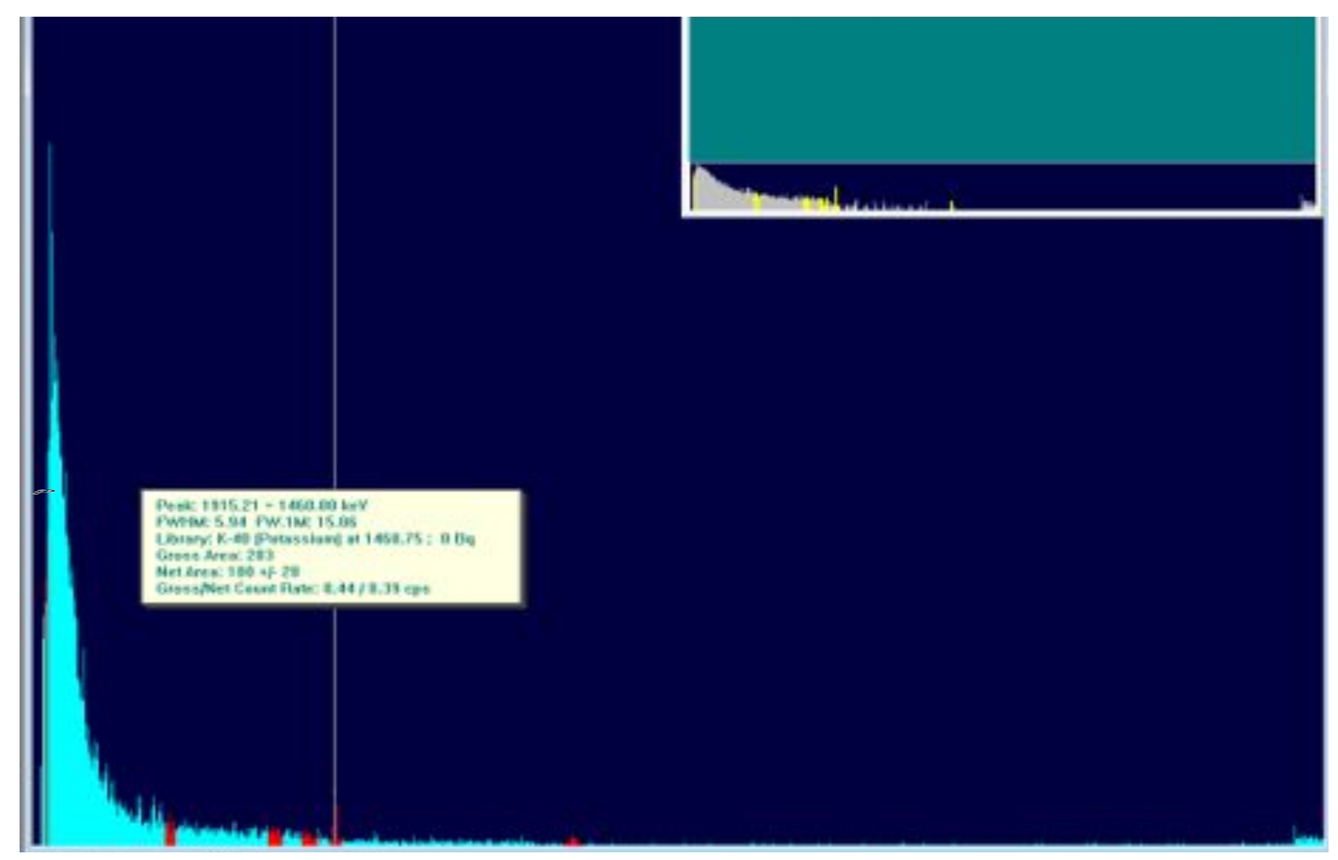

Figure 3 Photon Energy Output of Incident Gamma Rays

The average energy of each photon that was generated by the scintillator as a consequence of the gamma-ray interaction with the NaI crystal was found to be 3eV. A standard NaI crystal yield 40000 photons per MeV of input energy.

Therefore, for each MeV that strikes the scintillator, the output photon energy is 120,000 eV. Assuming an average efficiency of 20% for a standard photoelectric cell,

$$\frac{\text{Energy stored (in Mev)}}{\text{Input Energy (in MeV)}} = 0.12$$

The energy storage values for the usability of this system can be calculated based on the data regarding particle flux and energy at various distances from the Earth and the Sun mentioned in the next section.

For a Germanium-based system, the calculations for the energy stored is given by the equations below:

Charge carriers produced by Ge per unit energy deposited = 1/2.98

$$\text{Detector Current} = \text{Energy Rate}\left(\frac{eV}{s}\right) \times \underbrace{\frac{\text{charge (Q)}}{\text{energy (eV)}}} \times \underbrace{1.6 \times 10^{-19}\frac{\text{Coulombs}}{Q}}_{\text{Charge per charge carrier}}$$

$$\frac{\text{Detector Current (A)}}{\text{Energy Rate (MeV/s)}} = 10^6 \times \frac{1.6 \times 10^{-19}}{2.98}$$

$$= 5 \times 10\text{-}14 = 0.05\ \text{pA/ (MeV/s)}$$

H V

Cosmic Radiation and Solar Wind

From the conservation of mass and magnetic flux (assuming flux-freezing), we have along a solar wind streamline that intersects Earth:

$$n_0 v_0 = \left(\frac{B_0}{B_E}\right) n_E v_E$$

Using the empirical fact that the bulk kinetic energy provides the dominant contribution to the solar wind energy flux at 1 AU (see, e.g., Leer, Holzer, & Flå 1982), we may write the conservation of energy along the streamline as:

$$F_{w0} = \left(\frac{B_0}{B_E}\right) \frac{1}{2} m_p n_E v_E^3$$

According to the above equations, with an experimental solar wind flux of 3.8×10^8 protons/cm^{-2} s^{-1} at 1 AU, a proton moving with a speed of 440 km/s has an energy of ~1 keV. Thus, by most measures, solar wind ions are low-energy particles. The heliosphere is, nevertheless, filled with a number of energetic ion populations of varying intensities with energies ranging upwards from ~1 to ~108 keV/nucleon.

Element	Abundance Relative to Oxygen
H	1900 ± 400
He	75 ± 20
C	0.67 ± 0.10
N	0.15 ± 0.06
O	1.00
Ne	0.17 ± 0.02
Mg	0.15 ± 0.02
Si	0.19 ± 0.04
Ar	0.0040 ± 0.0010
Fe	019 + 0.10, − 0.07

Figure 4

As is evident from **Figure 4**, the flux of heavy ion radiation in solar wind is quite high at 1 AU from the sun, i.e. about the position of man-made satellites. The relative abundance values in **Figure 4** are long-term averages; however, abundances vary considerably with time. Even though the relative abundances are very high, the actual flux is almost negligible compared to other energetic charged particles like the proton.

It is observed that during a relatively quiet period, the solar wind at the level of earth contains approximately 1 to 10 protons per cubic centimetre moving outward from the Sun at velocities of 350 to 700 km per second; this creates a positive ion flux of 10^8 to 10^9 ions per square centimetre per second, each ion having an energy equal to at least 15eV. During solar flares, the proton velocity, flux, plasma temperature, and associated turbulence increase substantially. The associated energy flux can be converted by our system to usable electric energy.

Conclusion & Future Work

The objective of this experiment was to prototype a device for converting particle kinetic energy into storable energy. After a design, testing, and revision process, a final system was developed and assembled. During data collection and analysis, a C++ script was used to analyze and plot the data. Due to time constraint, further experimentation is required to make a more accurate statement on the practicality of such a design. We would like to analyze the scintillator output using heavy-ion particle beams. This is available at the BASE Cyclotron 88 at the Lawrence National Berkeley Lab. We would also like to work on testing different scintillator crystals to optimize output energy.

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