Development of compact Tissue Equivalent Proportional Counter (TEPC) for monitoring space radiation in the ISS, Cubesat and Aircraft

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Introduction

- NASA proposed the development of ISS radiation monitoring detectors as a Korea-NASA cooperation program in 2009.

- **KASI (Korea Astronomy Space and Science Institute)** has been funded $200k a year for developing TEPC since 2011 and it will be completed in 2016.

- In 2015, we will launch a cubesat (~3 kg) aboard the TEPC, and in 2017 we will launch a small satellite (~100 kg) for high LET cosmic ray measurements.

- We will also extend our research area to the monitoring space radiation on aircraft altitude.
We have developed several models of TEPC and the instrument is still under improvement.
**Brief Description of TEPC**

- **Type:** Spherical Tissue Equivalent Proportional Counter
- **Tissue Equivalent Material:** A-150
- **Out Diameter:** 40 mm
- **Inner Diameter:** 30 mm
- **Internal Tissue Equivalent Gas:** 100% \( \text{C}_3\text{H}_8 \)
- **Pressure:** 27.7 torr
- **Simulated Site Diameter:** 2\( \mu \)m
- **Anode:** 30 \( \mu \)m Stainless wire
- **SUS304 Stainless Housing**
- **Diameter:** 54 mm
- **Thickness:** 1.5 mm
# Improvement of TEPC

<table>
<thead>
<tr>
<th></th>
<th>Model-2013</th>
<th>Model-2014</th>
<th>Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Volume/Mass</strong></td>
<td>2,624 cm³ / 1.8Kg</td>
<td>1,480 cm³ / 1.5Kg</td>
<td>&lt; 6,000 cm³</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>&lt; 5 Kg</td>
</tr>
<tr>
<td><strong>Power</strong></td>
<td>4.9 W</td>
<td>2.5W (Battery)</td>
<td>Low Power</td>
</tr>
<tr>
<td><strong>Signal Processing</strong></td>
<td>Analog Pulse Processing</td>
<td>Digital Pulse Processing</td>
<td></td>
</tr>
<tr>
<td><strong>Gain Channel</strong></td>
<td>Single Gain</td>
<td>Two Gain Channel (64/1.1)</td>
<td></td>
</tr>
<tr>
<td><strong>Interface</strong></td>
<td>TCP/IP</td>
<td>RS232</td>
<td></td>
</tr>
</tbody>
</table>
Manufacturing
Thermal Vacuum Test

- Temperature Requirement of ISS
  - +5℃~ +40℃
  - Operating Temp: +20℃
  - 1 cycle
Mechanical Analysis

1st mode 249 Hz  
2nd mode 352 Hz  
3rd mode 635 Hz  
4th mode 823 Hz  
(NASA requirements: Payload > 100 Hz)

* Quasi-static  
Load(Design):  
53G (Max. 32MPa)

Max. 0.6MPa (PCB support/SUS304)

* Quasi-static  
Load(Design):  
53G (Max. 175MPa)

Max. 3.3MPa (PCB support/SUS304)
Vibration Test

<table>
<thead>
<tr>
<th>Test Type</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Random Vibration</td>
<td>3.6 (grms)</td>
</tr>
<tr>
<td>Shock Level Test</td>
<td>9 (g-load)</td>
</tr>
<tr>
<td>Number of Shock</td>
<td>10</td>
</tr>
</tbody>
</table>

TEPC passed successfully the vibration and shock test required for ISS.
Equivalent Dose Calculation Protocol

1. **Cf-252 Standard Source**
2. **Known Equivalent Dose** ($H_{\text{cal}}$)
3. **Measured Spectra for Standard Source**
   - High & Low Gain Spectra
4. **High Gain Spect.** + **Low Gain Spect.**
5. **Sum Spectrum in 0.1 - 500keV/\mu m**
6. **Lineal Energy-channel calibration** $y = \frac{E}{I}$
7. **Freq. Probability density**; $f(y)$
8. **Dose-mean lineal energy**; $\bar{y}_D = \int_{y_{\text{min}}}^{y_{\text{max}}} y f(y) dy$

9. **Absorbed Dose**; $D = \frac{2\bar{y}_D}{\sum_{m} N}$
10. **Equivalent Dose (ICRP 60)**; $H_{\text{non-cal}} = DQ$

11. **Spectrum for Unknown Source (Rx)**
    - $f(y) \rightarrow y_D \rightarrow Q \rightarrow D \rightarrow H_{\text{unknown}}$

12. **Calibration Factor** $k_f = \frac{H_{\text{cal}}}{H_{\text{non-cal}}}$
13. **Equivalent Dose**; $H = H_{\text{unknown}} k_f$
HIMAC Experiments

Experimental set up in HIMAC bio beam line
Gas Multiplication

Pulse height spectra and gas multiplication of C-135 MeV/u ions as a function of applied voltage

\[ \text{Gas Gain} = \frac{\text{No. of } e \text{ per channel} \cdot \text{proton drop point channel}}{\varepsilon / W} \]
Measured LET Spectra from C-135 beam line

(a) Frequency distribution

\[ \bar{y}_F = \int_{y_{\text{min}}}^{y_{\text{max}}} yf(y)\,dy = \frac{\sum_{i} y_i N_i}{\sum_{i} N_i} = 14.0\text{keV/\micro m} \]

(b) \( yd(y) \) micro-dosimetry spectrum

\[ \bar{y}_D = \int_{y_{\text{min}}}^{y_{\text{max}}} yd(y)\,dy = \frac{1}{\bar{y}_F} \int_{y_{\text{min}}}^{y_{\text{max}}} y^2f(y)\,dy = \frac{\sum_{i} y_i^2 N_i}{\sum_{i} y_i N_i} = 20.5\text{keV/\micro m} \]
Space Radiation Experiments on LEO satellites

- Korean Cubesat Program
  - Spacecraft Developed by Kyunghee University
  - KASI provides TEPC as a main payload
  - Launch in 2015

- Korean Small Satellite Program
  - Spacecraft Developed by KAIST
  - KASI provides TEPC as an payload
  - Launch in 2017
Dose Estimation in LEO (science mission)

We estimated low altitude dose rate from the Van Allen Probes mission data. Geo-magnetic field effectively shields the most solar energetic protons.

However, what happen for high LET particles that have large gyro-radii?
We have measured space radiation on the altitude of 30,000 ft in the Korean Peninsular with Liulin-6.

In the future, we will do the measurements with our own TEPC.
Conclusions

- A TEPC was designed and fabricated with A-150 ionization cavity, preamp + amplifier circuit, spectrometer, and HVPS for micro-dosimetry in ISS.

- The TEPC has been characterized and calibrated by using C-135MeV/u ions in HIMAC.

- We confirmed that the TEPC was well operated below 100 keV/μm.

Applications
- Cubesat launched in 2015
- Korean small satellite, NEXTSat-1 launched in 2017
- Air Crew Radiation Monitoring

Even though we cannot send our TEPC to ISS, we will measure space radiation on the aircraft altitude (~10 km) and LEO (~700 km). We think these experiment would be valuable in understanding radiation environment at the ISS altitude (~350km).