Development of a Timepix-Based Radiation Monitor for Analyzing Cosmic Radiation on Commercial Aircraft

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Background

The earth is constantly subjected to cosmic radiation, which is composed of high-energy particles originating from the sun and beyond our solar system. High levels of cosmic radiation can pose various biological risks, especially in cases of prolonged exposure. The atmosphere and magnetosphere provide protection from this radiation at ground level, but dose rate increases rapidly with altitude and geomagnetic latitude.

Airline pilots and crew are exposed to significantly higher cosmic radiation levels than the general public. In 1991, International Commission on Radiological Protection (ICRP) released a publication recommending aircrew be considered occupationally exposed[1]. Since, several studies have been conducted to monitor dose to aircrew. With the development of more advanced radiation detectors, continued measurement and characterization is necessary to verify, expand, and improve upon previous experimental results and predictive computer models.

The Timepix Detector

The Timepix is a hybrid pixelated silicon radiation detector developed by the Medipix2 collaboration at the European Organization for Nuclear Research (CERN).

- A monolithic Si-sensor is connected to the Timepix's 256 x 256 matrix of 55 μm^2 pixels by solder "bump-bonds."
- When a particle deposits energy above a certain threshold, it generates a Time Over Threshold (TOT) count proportional to the deposited energy.
- The Timepix captures frames, or "snapshots," of the radiation environment at a specified rate.
- The technology allows for characterization of the tracks of individual particles for detailed analysis.

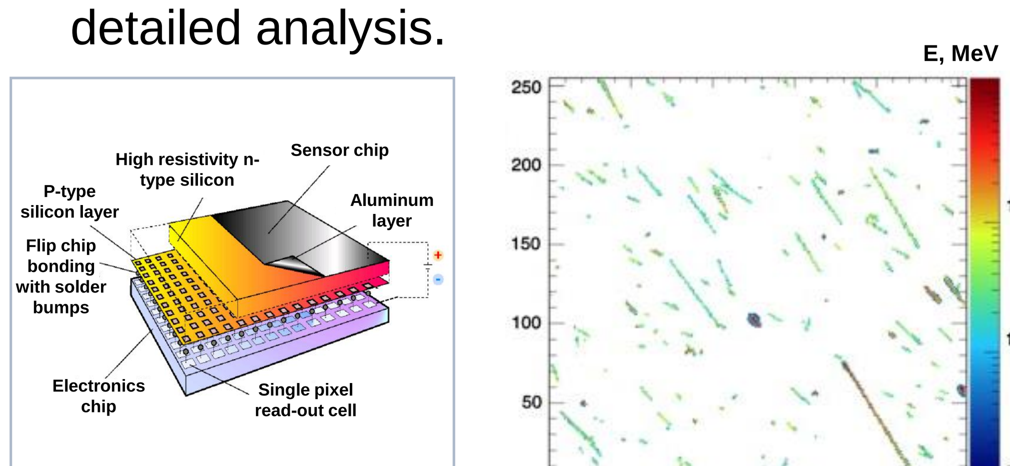

Fig. 1. Schematic diagram of Timepix chip (left) and example frame visualization from Kroupa et al.[2] showing individual particle tracks (right).

Development / Methodology

I developed a dosimeter consisting of a Timepix radiation detector connected via USB interface to a Raspberry Pi 3 minicomputer. The device has the advantage of being light, compact, and easy to operate for convenient usage on aircraft. It was taken on board three intercontinental flights by members of Dr. Lawrence Pinsky's research group and one NASA WB-57 high-altitude research flight.

Fig. 2. Prototype radiation dosimeter consisting of a Timepix detector and Raspberry Pi 3 minicomputer.

The development process involved:

- Programming the Raspberry Pi to control Timepix frame acquisition and process, analyze, and store data.
- Extensive testing for consistency and reliability using radiation sources in UH and Johnson Space Center laboratories.
- Implementing software safety measures to ensure proper data management and reboot procedure in case of power interruption.

For data analysis, the silicon dose was converted to tissue equivalent dose using the method described in Stoffle et al[3]. To plot the data, dose rate was averaged over every 250 seconds. Average dose rate and total dose were calculated for each flight, and total dose was compared to CARI-6, EPCARD, and SIEVERT online model predictions. Aircraft position data was acquired from flightaware.com.

Results

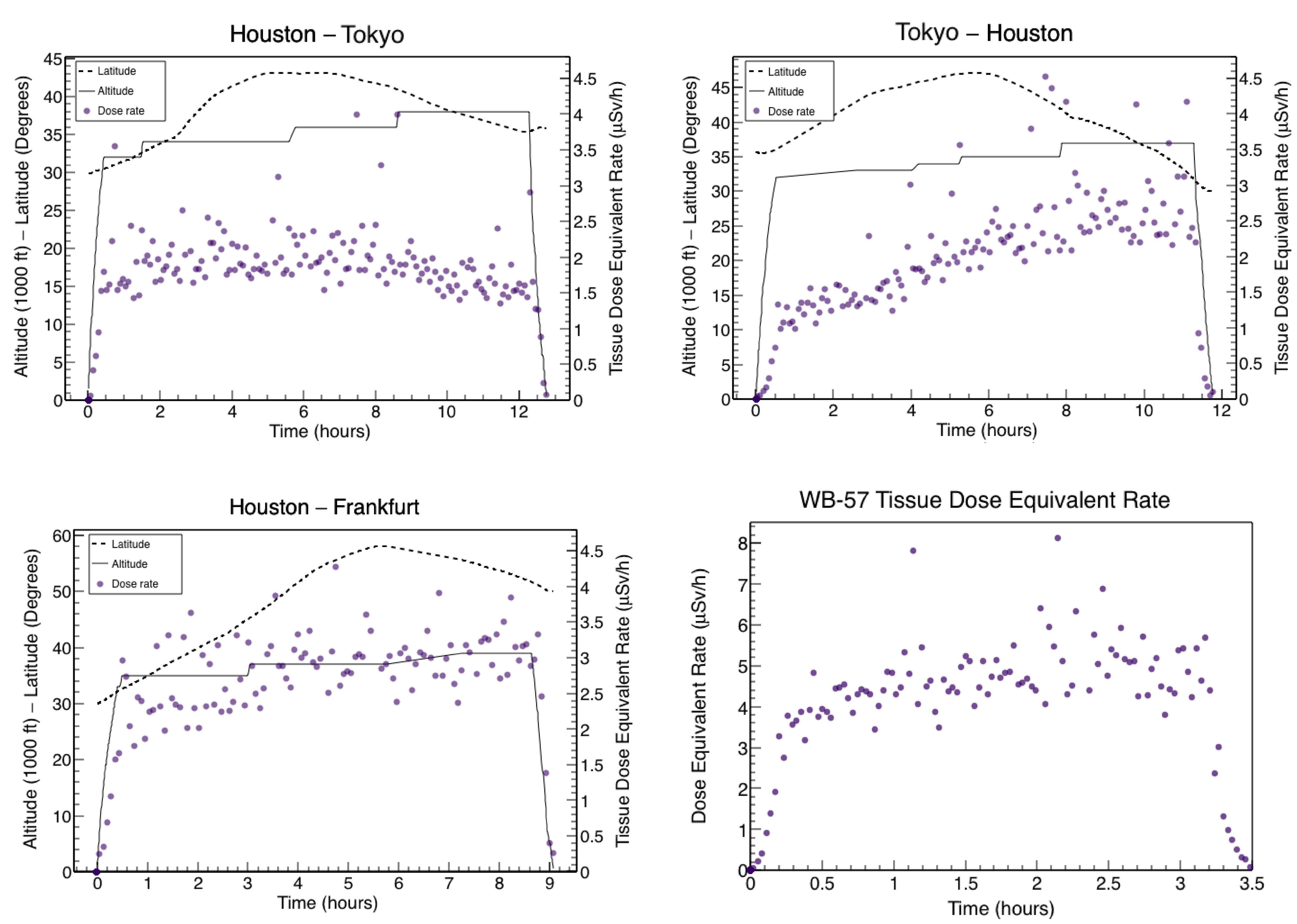

Fig. 3. Flight profiles and tissue equivalent dose rates for Houston-Tokyo, Tokyo-Houston, Houston-Frankfurt, and WB-57 flights. Position data for the WB-57 flight was unavailable, but these flights typically reach altitudes up to 60,000 ft. The average dose rates were 1.82, 1.89, 2.58, and 4.14 µSv/h, respectively.

Results (cont'd)

Table 1. Total experimental tissue dose equivalents compared to values calculated by online codes for each route (in µSv).

Route	RPi Dosimeter*	CARI-6	EPCARD	SIEVERT
Houston → Tokyo	22.8 µSv	66.05 µSv	77 µSv	82.5 µSv
Tokyo → Houston	22.5 µSv	59.11 µSv	70 µSv	90.9 µSv
Houston → Frankfurt	23.2 µSv	66.13 µSv	78 µSv	81.0 µSv

*Uncorrected for neutron dose

Experimental tissue dose equivalent rates were significantly lower than those predicted by online codes. This is likely a result of inaccurate representation of neutron dose, which requires separate analysis due to complex interactions in the Timepix detector.

Conclusions

My device performed reliably on the four flights taken during the research period. The measured data followed expected latitude and altitude trends, but the total flight doses were lower than those calculated by online computer models. The method used for converting silicon dose to tissue equivalent dose was created for the charged particle environment in space, but the additional neutron component at aviation altitudes requires a different approach. The method currently in development utilizes Geant4 particle simulations to evaluate the Timepix response to neutrons and determine an appropriate calibration.

References

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