enhanced Active Tissue Equivalent Dosimeter (eATED) for Space Crew Dosimetry

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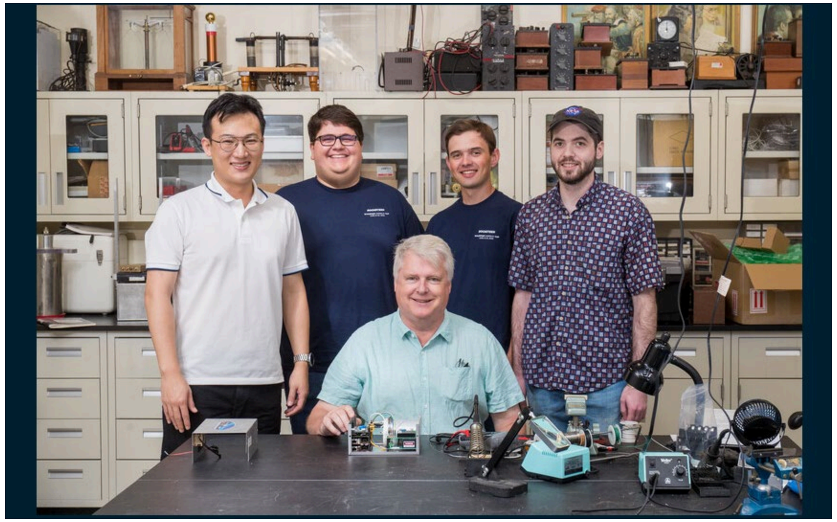
The Atmospheric Ionizing Radiation Environment (AIRE) Institute



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The Atmospheric Ionizing Radiation Environment (AIRE) Institute

Mission Statement: The Atmospheric Ionizing Radiation Environment (AIRE) Institute's mission is to promote research and education on the Steady State Atmospheric Ionizing Radiation Environment (SSAIRE), its effects on life, on our technological infrastructure and on the environment.

The Atmospheric Ionizing Radiation Environment (AIRE) Institute

- Established at Oklahoma State University in 2021.
- Only group in the USA dedicated to studying the Steady State Atmospheric Ionizing Radiation Environment (SSAIRE).
  - US is behind many other countries (especially in Europe) in this area.
- Different focus from traditional Cosmic Ray research:
  - emphasis is on lower energy SSAIRE, not on higher energy Extensive Air Showers,
  - includes geomagnetic effects, Solar Particle Events (SPE), space weather effects (e.g. Forbush decreases, geomagnetic storms, diurnal effects), Terrestrial Gamma Flashes (TGF) and related thunderstorm phenomena.
- The AIRE Institute is not advocating more regulation (e.g. radiation exposure limits for air crew).
- The AIRE Institute is advocating the need for expanded research into SSAIRE phenomena.

AIRE Institute Research Goals

- Further our understanding of SSAIRE through a combination of measurements and models.
- Develop, characterize and fabricate a suite of low-cost, easy-to-use instruments that can be widely deployed on a range of airborne, space-borne, and ground-based platforms, and make these instruments available to the aviation and space weather communities.
- Further develop the AIREC computer model to better our theoretical understanding of the temporal and spatial structure of the SSAIRE, both from GCR and SPE.
- Investigate other sources of ionizing radiation in the atmosphere, e.g. those associated with thunderstorms.
- Work with Space Weather community to implement Research to Operations (R2O) monitoring and modeling capabilities in the atmosphere.

Airborne, Space-borne and Ground-based Platforms

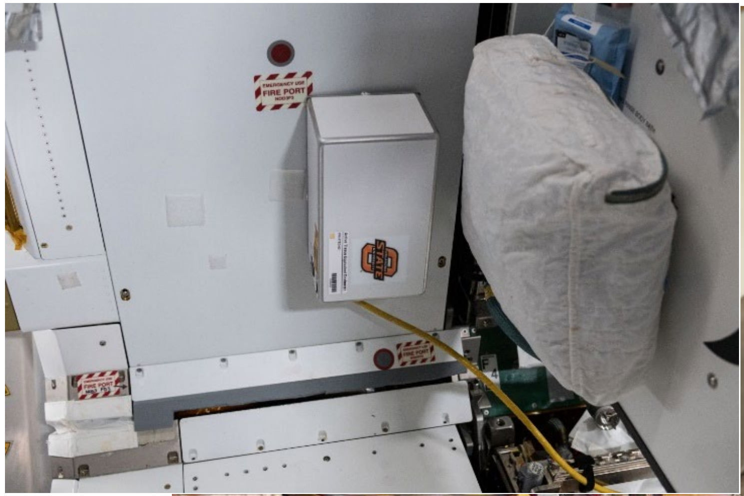
- Commercial, business and military aircraft,
- High altitude research aircraft (NASA WB-57 and ER-2),
- High altitude UAVs (Swift Aerospace HALE, RQ-4 Globalhawk),
- High altitude research balloons (NASA polar balloon missions, Raven Aerospace),
- Suborbital spacecraft, including space tourism (Blue Origin New Shepard, Virgin Galactic),
- Ground-based cosmic ray monitors (neutron and muon),
- Near space amateur balloons and rockets,
- Low Earth Orbit (ISS, SpaceX, cubesats),
- Individual pilots, flight attendants, passengers.

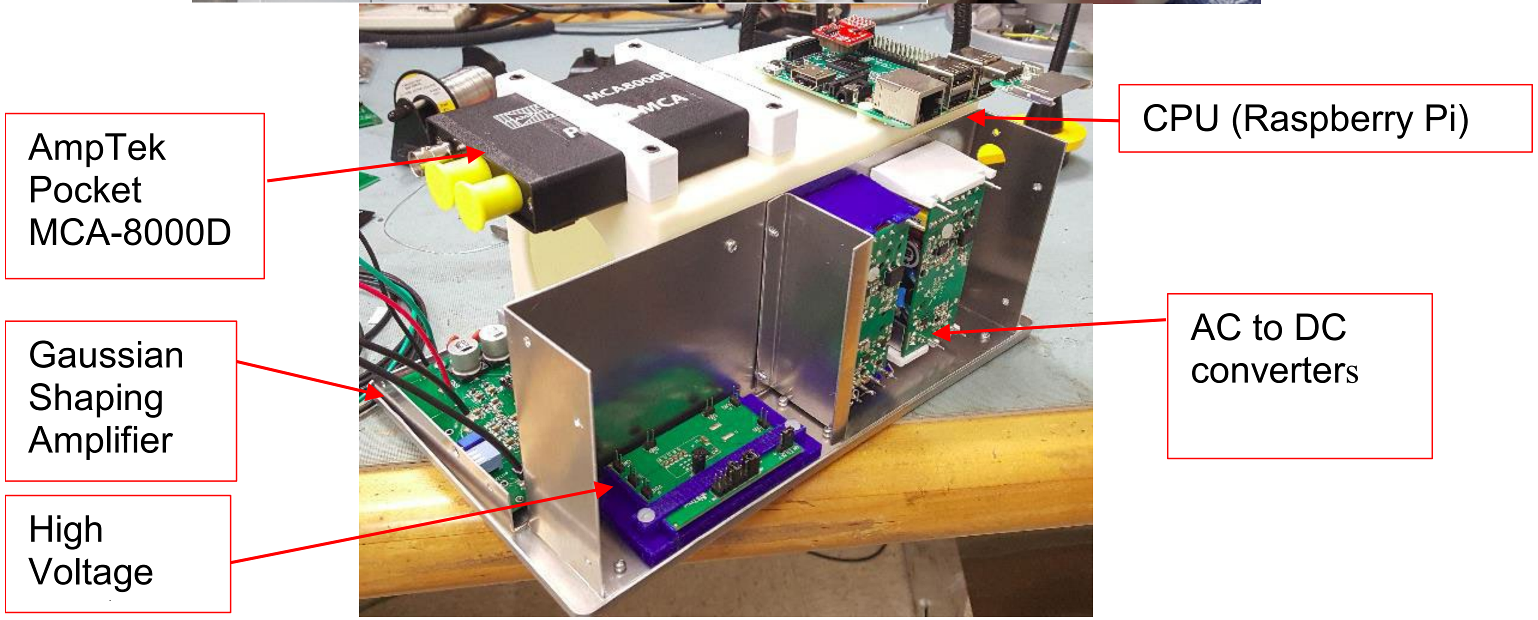
OSU EVB RPL

eATED Description and Objectives:

- **Scientific Merit:** Demonstrate the eATED tissue equivalent proportional counter (TEPC) and Si PIN diode with sensitivity low and high LET ionizing radiation.
- **Technical Description:** The low-cost, self-contained, and portable eATED is sensitive to ionization radiation, including secondary neutrons, of the types and energies encountered in space and can provide real time dosimetric data on space crew radiation exposure.
- **Physical Description:** eATED is self contained in a flight qualified aluminum box and requiring only external power.
- **Objectives**: Fabricate, test, characterize and calibrate eATED, implementing lessons learned from the 2018 ISS ATED experiment including a newly designed ionization cavity to reduce microphonic noise and adding a capability to detect lower LET radiation (not completely registered in the TEPC) via Si PIN diode.
- **Implementation:** eATED will be positioned in a quiet location within the habitable volume of ISS and operate continuously for ~6 months. Data would be periodically downloaded to ground via an ISS laptop.

2018 ISS ATED Experiment





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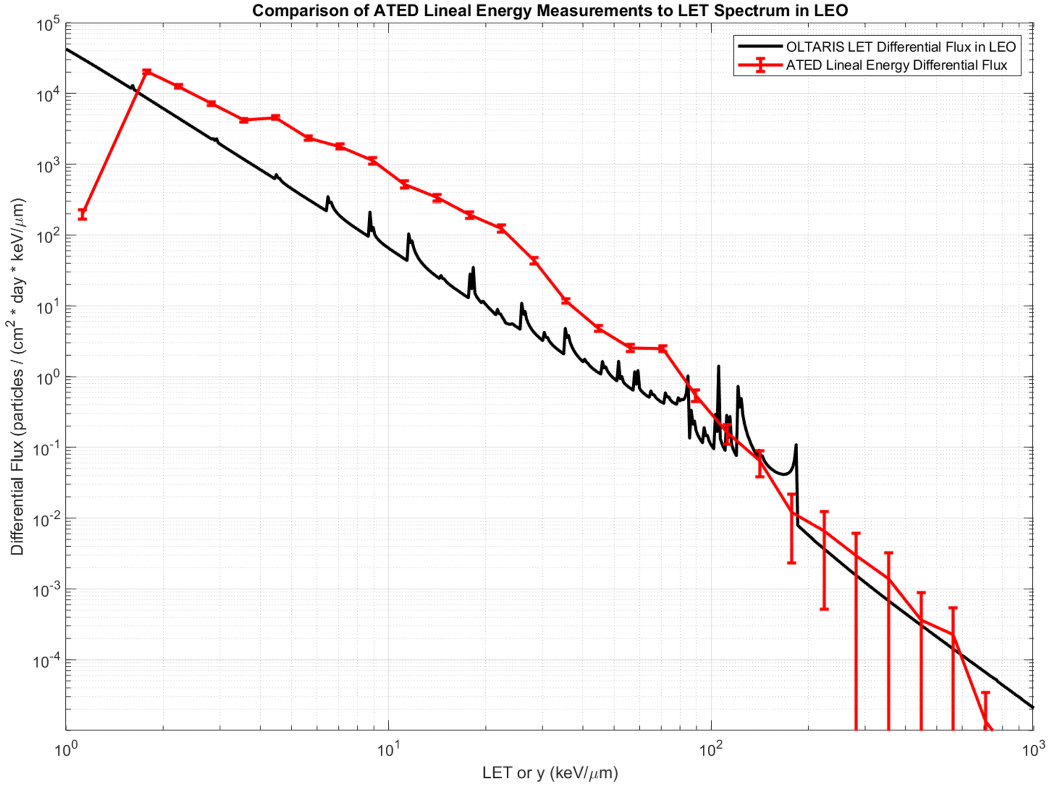
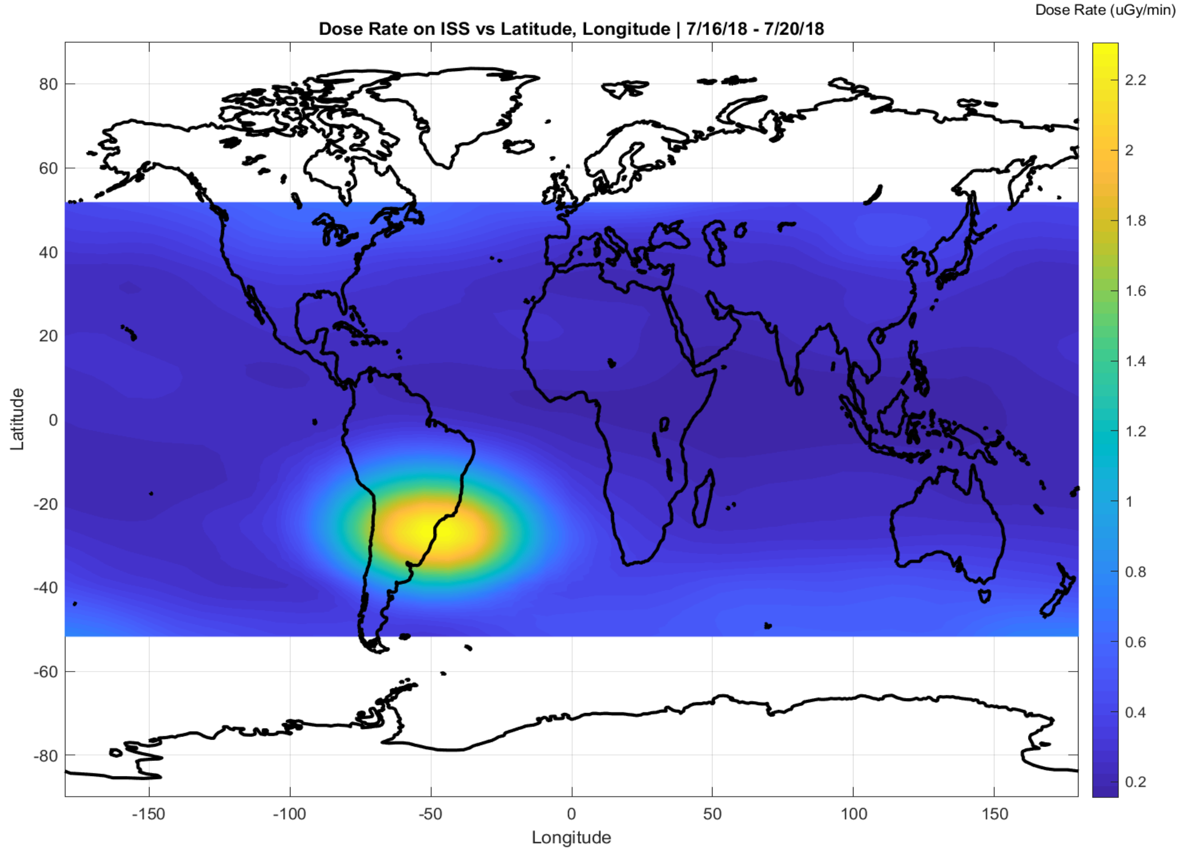
Results for 2018 ISS ATED Experiment

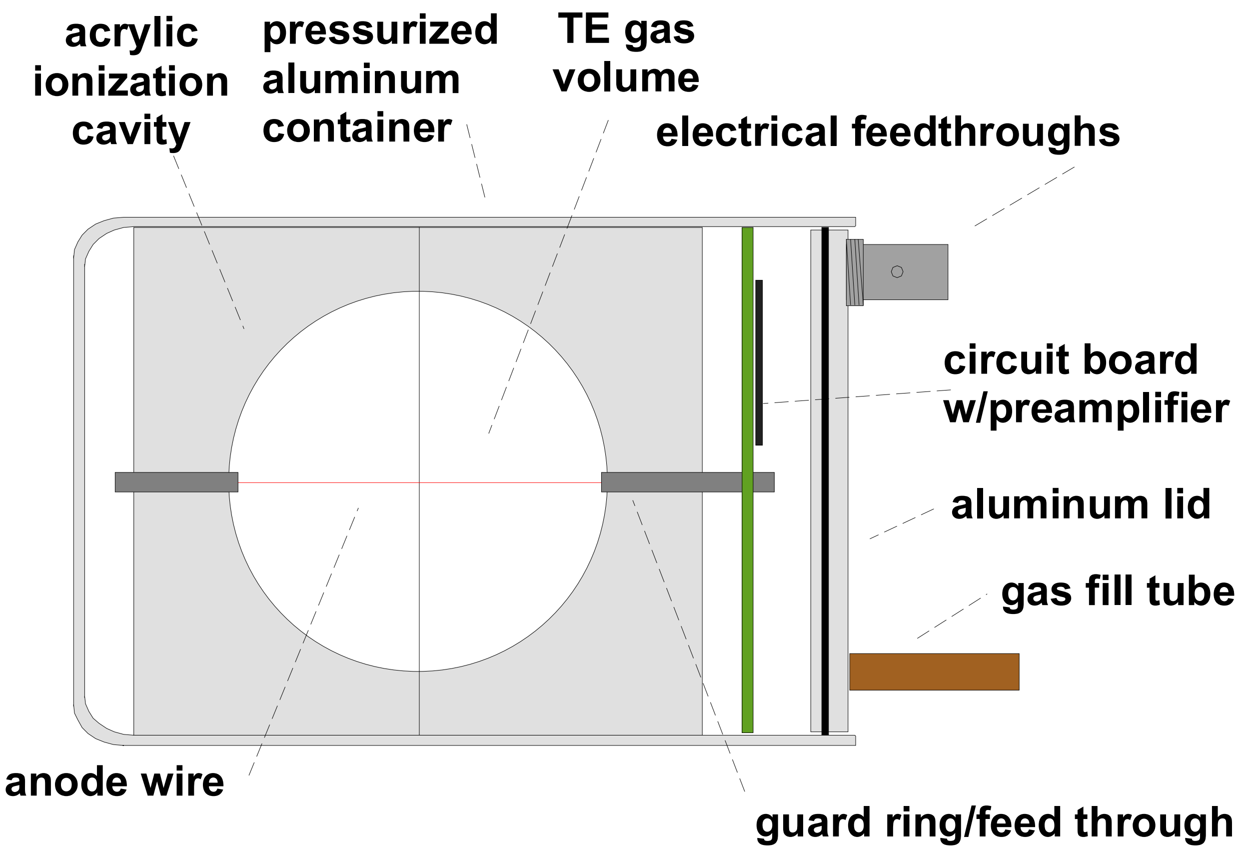




Lesson Learned from 2018 ISS ATED Experiment

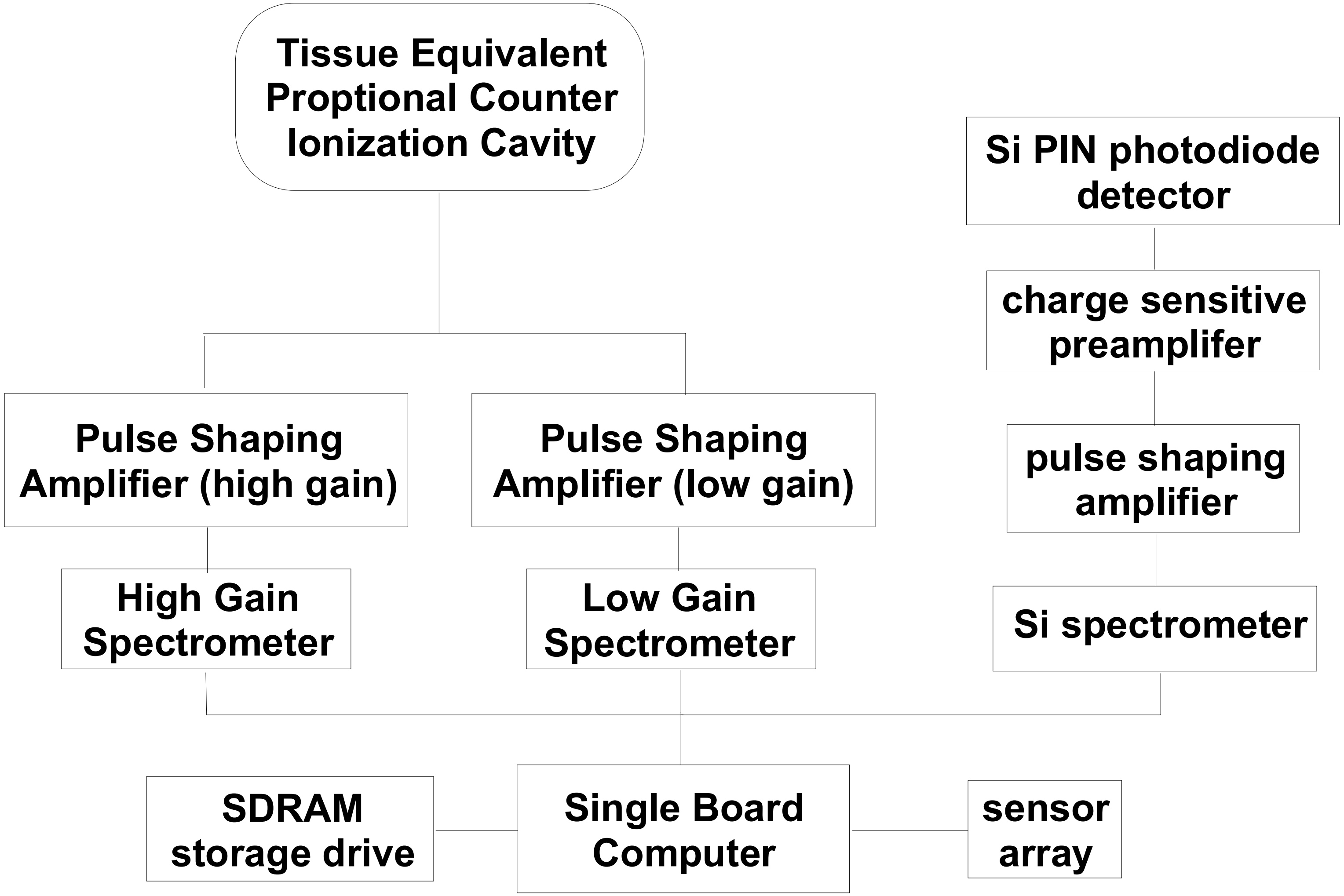
1. Cover the SDRAM drive with a protective cover so that drive and card are not vulnerable to damage from being inadvertently kicked or knocked by crew.
2. Locate ATED in safer location, i.e. out of high traffic areas.
3. Locate ATED far away from possible sources of microphonic noise.
4. Redesign ionization cavity and central anode wire to decrease susceptibility to microphonic noise.
5. Use two separate amplifiers and input channels in order to separate and better sample high and low regions of the lineal energy spectrum.
6. Obtain informal review of design by current or former current crew members in order to solicit feedback and suggestions to improve the design and minimize design weaknesses (we suggest that this lesson learned be applied to all ISS EPSCoR payloads).

New eATED Detector Head Design

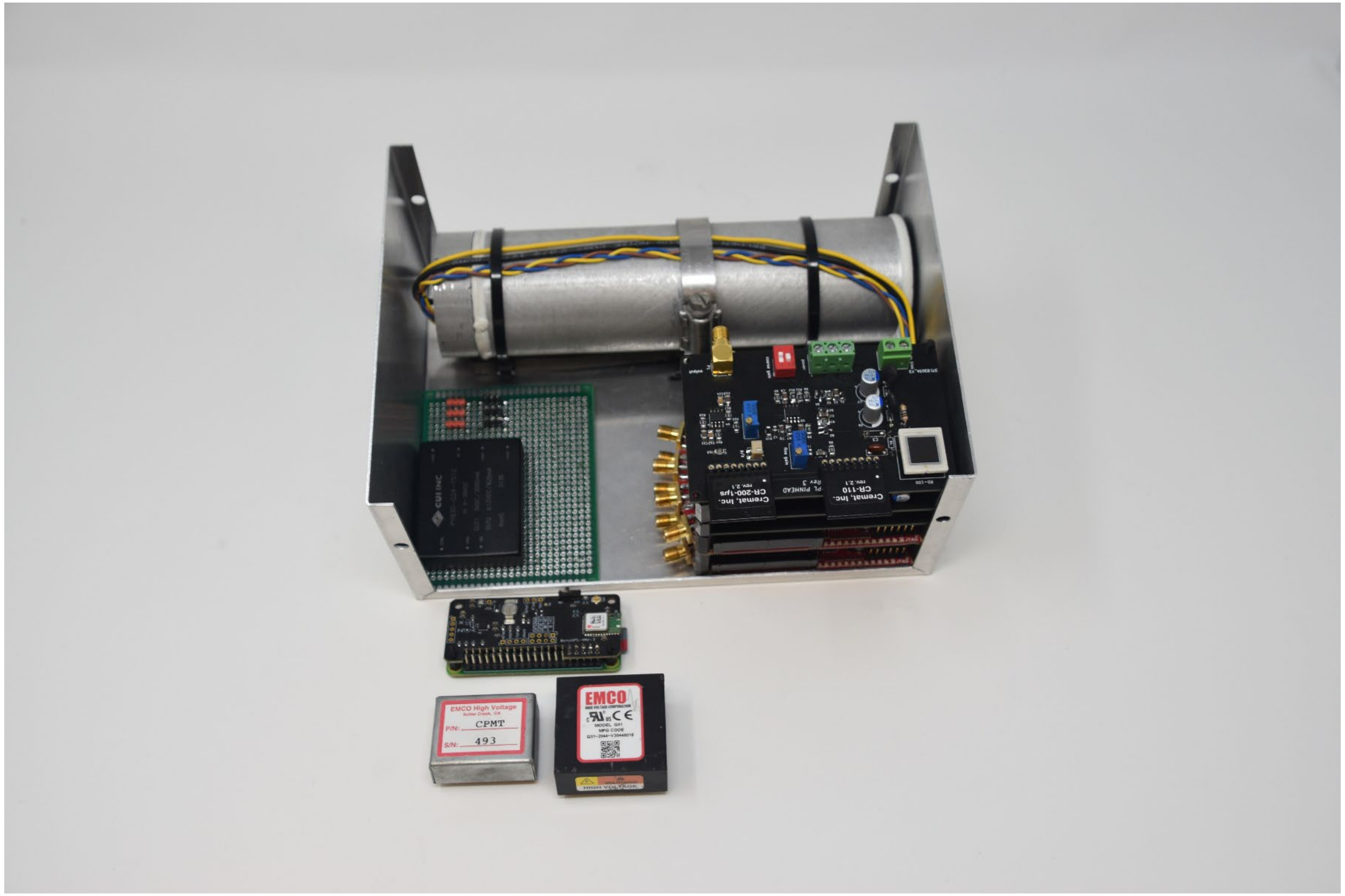


- Ionization cavity is made by hollowing out hemispherical volumes in two pieces of cylindrical acrylic and placing them together to make a spherical cavity.
- Anode wire is 2 mil Tungsten…stiffer than the 2 mil stainless steel used in ATED.

Block Diagram of eATED Detector with low LET Si Detector

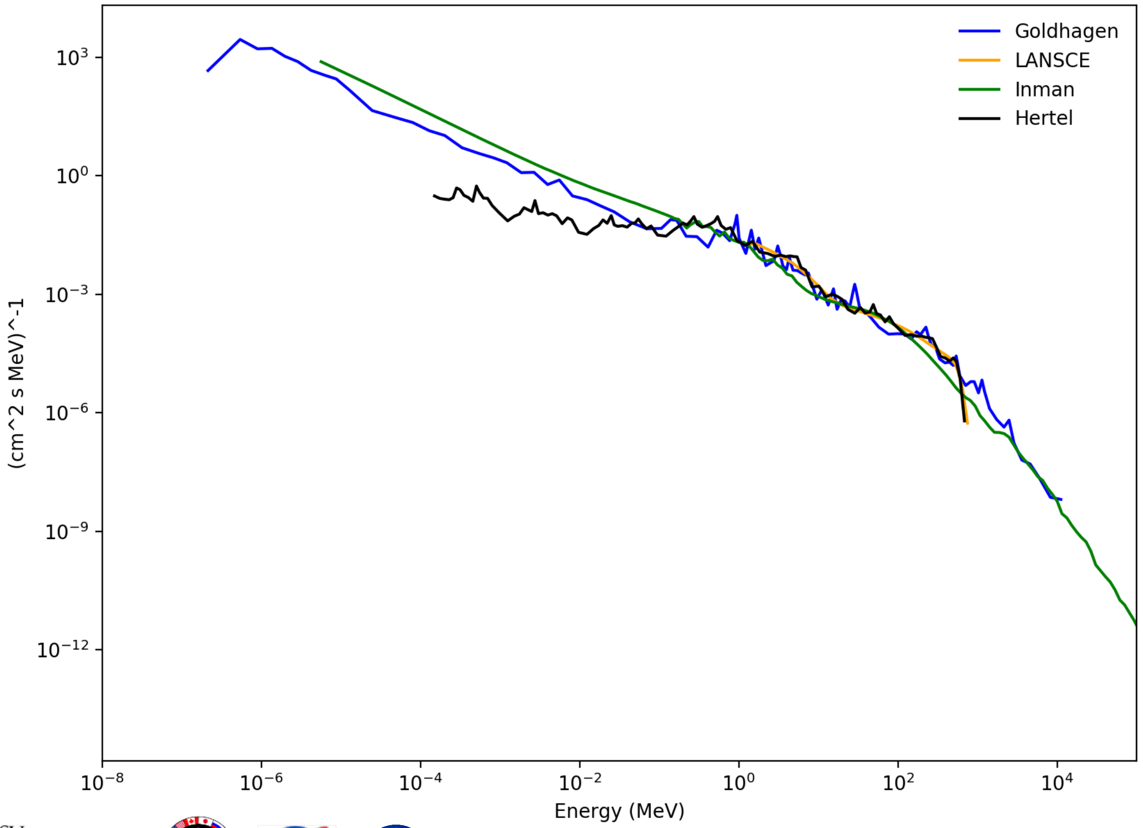


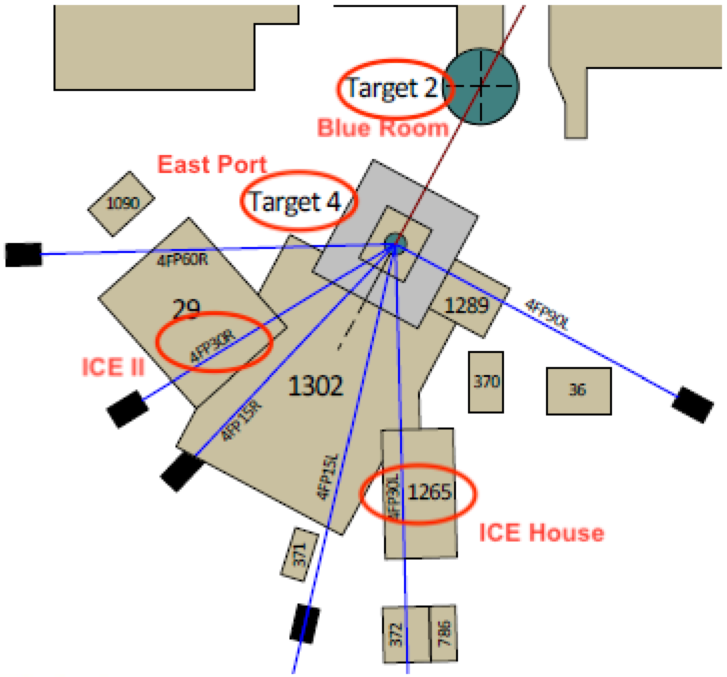
eATED Engineering Prototype (incomplete)

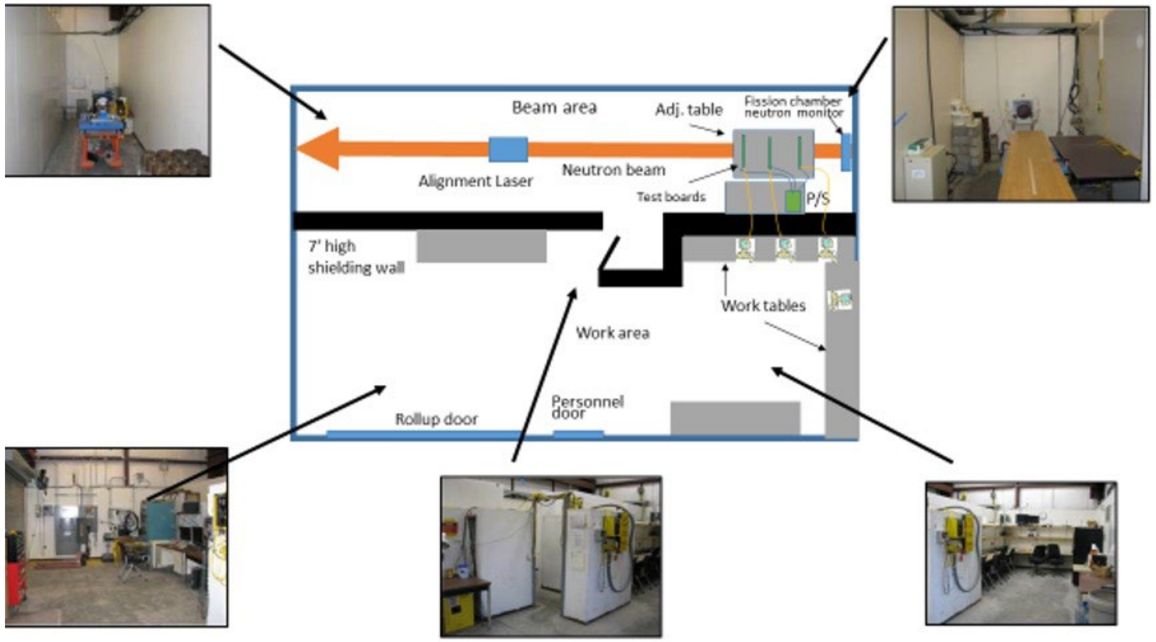


Los Alamos Neutron Science Center (LANSCE) ICE House Flight Path 30L

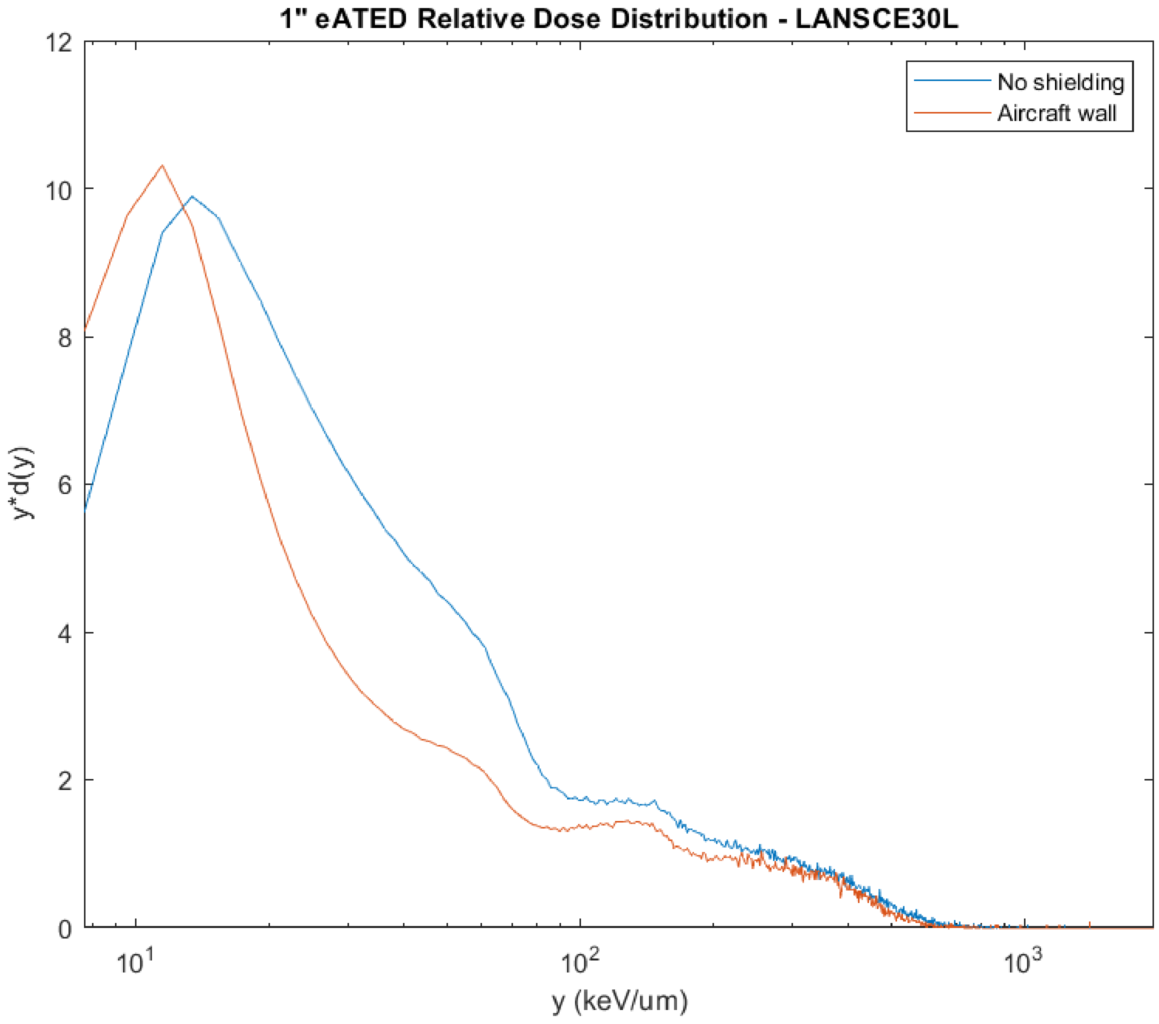
- similar neutron energy spectrum ≤800 MeV.
- 10^6x higher flux than actual environment.

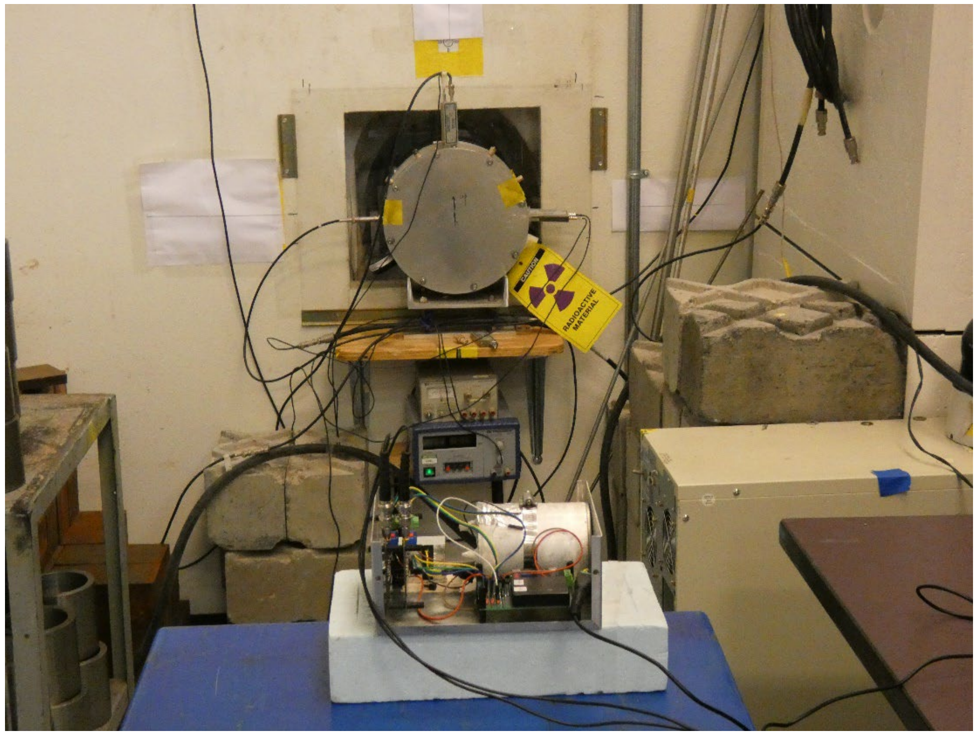






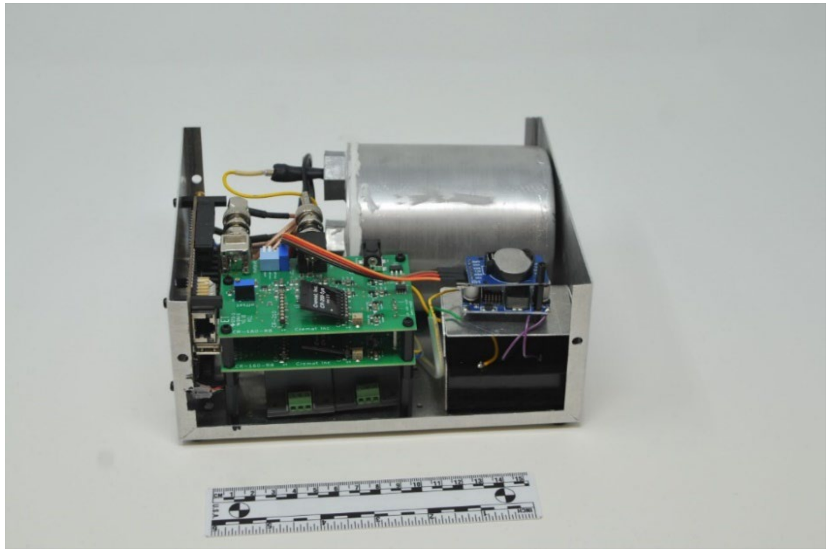
AirTED Prototype in LANSCE 30L Beam

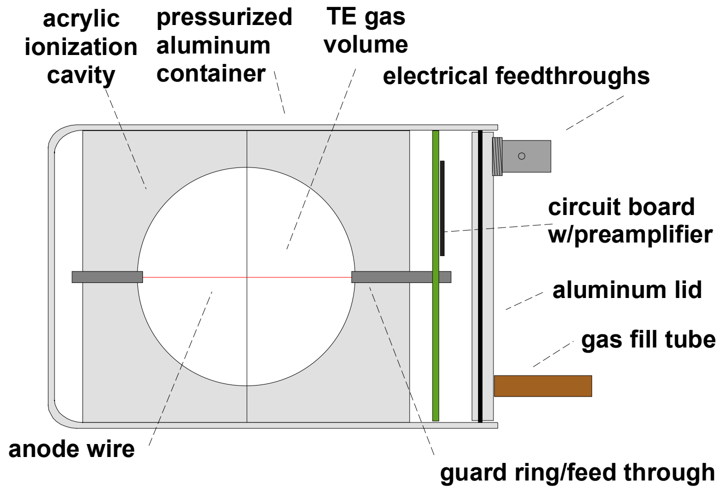




August 2022 experiment

Atmospheric ionizing radiation Tissue Equivalent Dosimeter (AirTED) Tissue Equivalent Proportional Counter on NASA WB-57

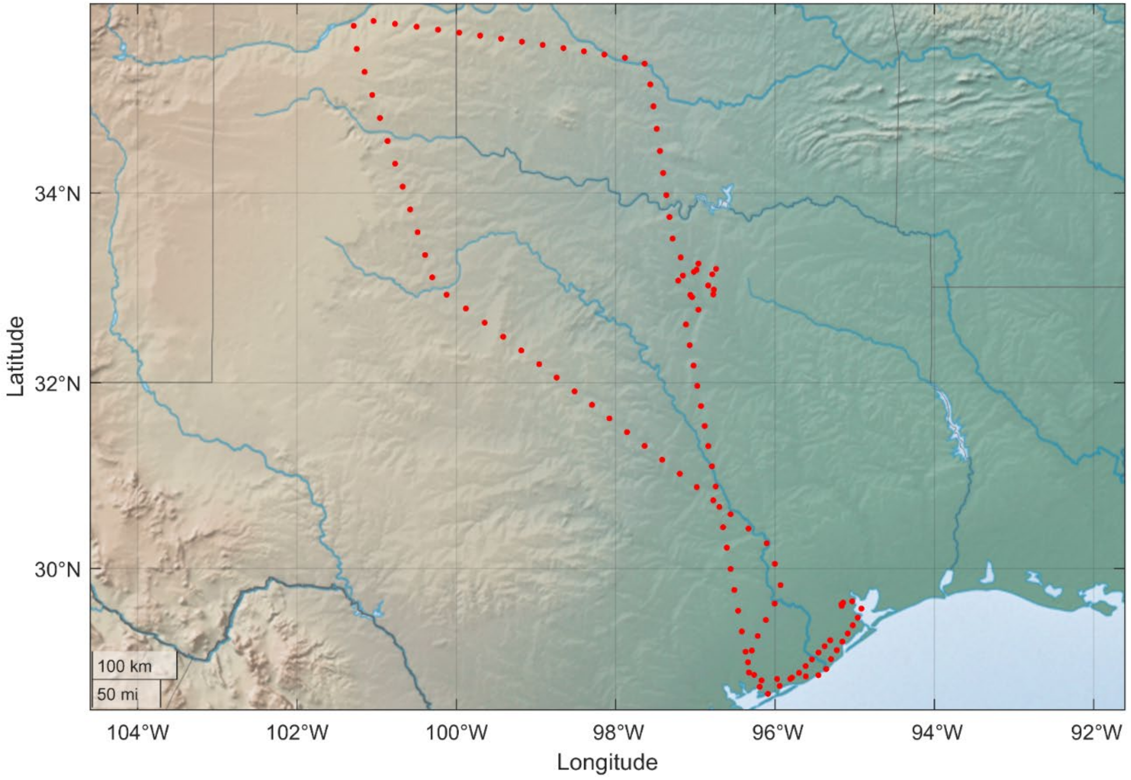


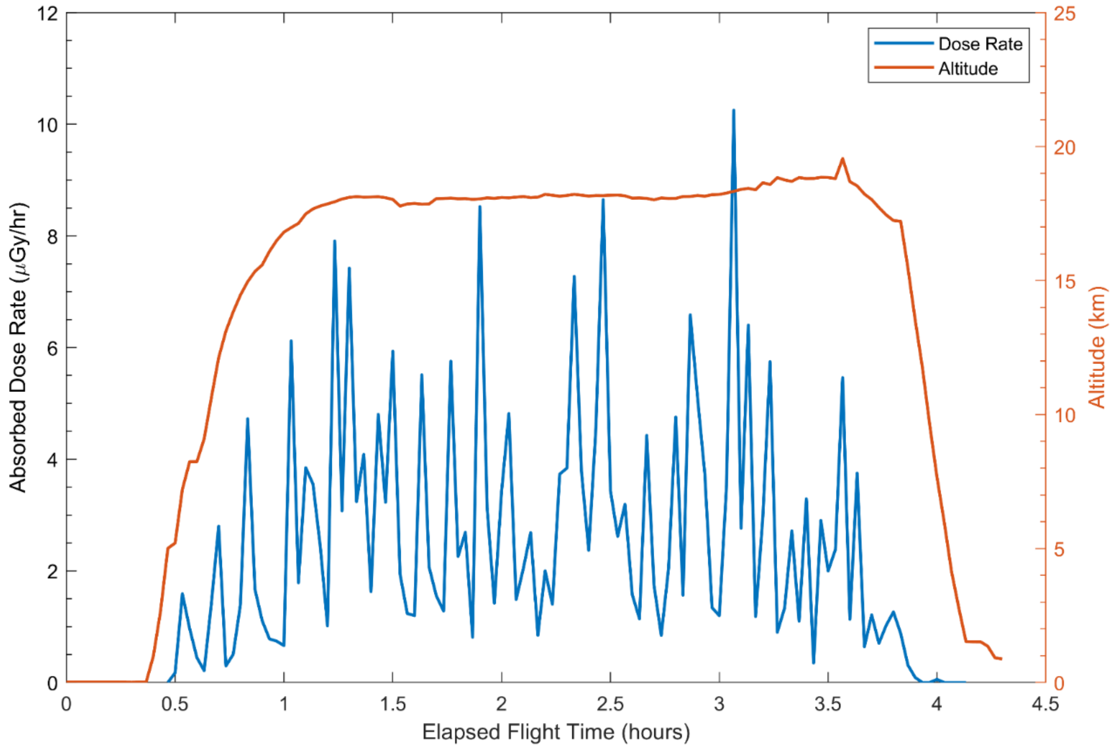


Credit: NASA

Credit: NASA

AirTED Flight on NASA WB-57, 20 January 2022





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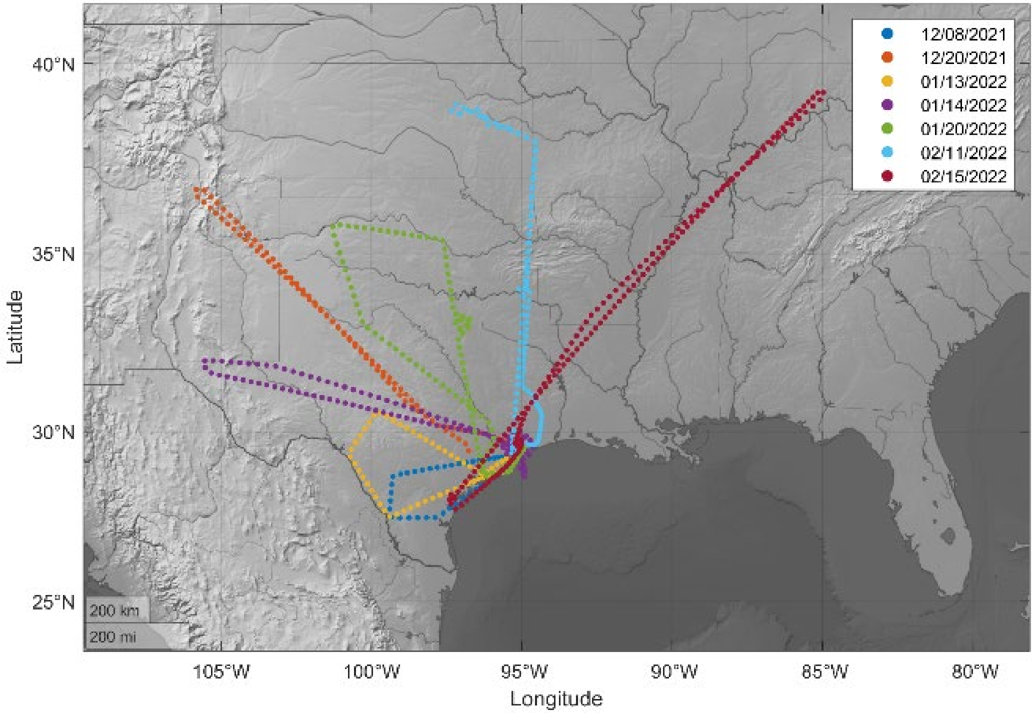
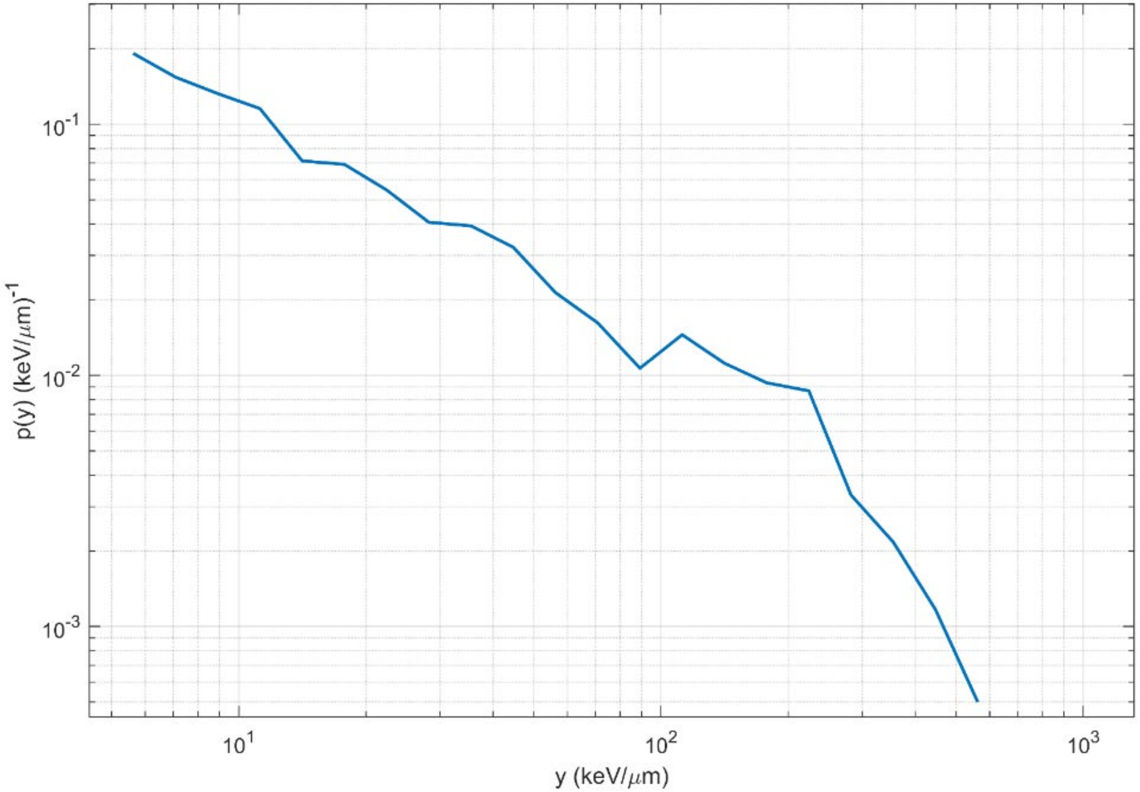
AirTED TEPC
Combined Lineal Energy Spectrum from seven WB-57 Flights





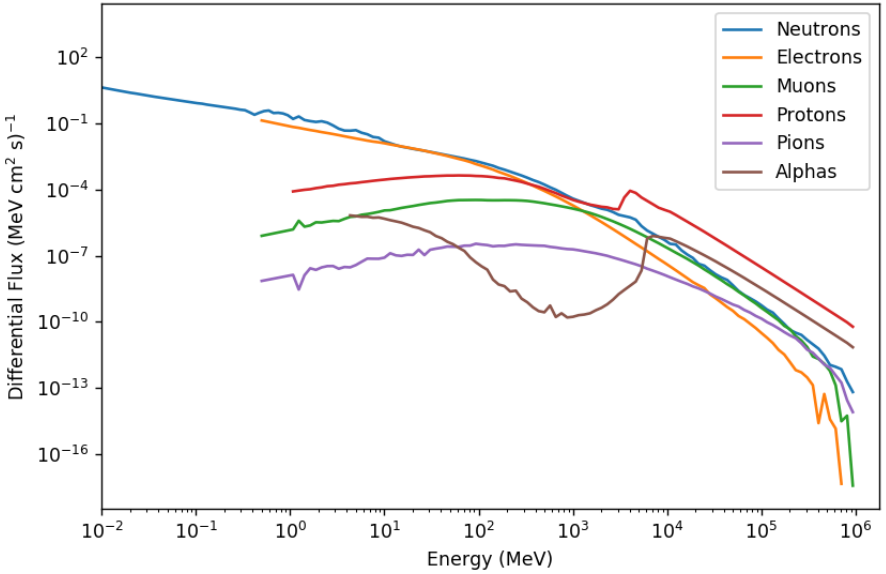
AirTED Measurements and CARI-7A modeled absorbed dose and average dose rates for seven WB-57 flights

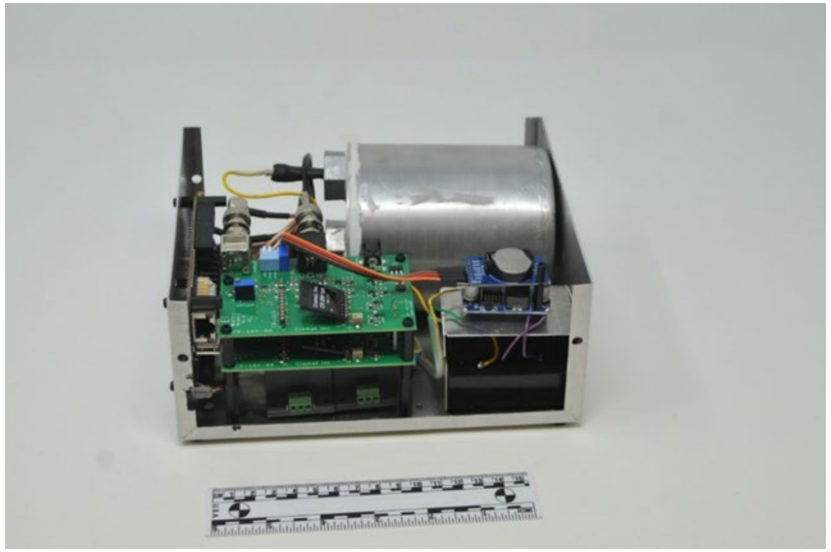
Flight Date	12/8/ 2021	12/20/ 2021	1/13/ 2022	1/14/ 2022	1/20/ 2022	2/11/ 2022	2/15/ 2022
Flight Duration (hrs)	1.36	3.76	1.96	3.33	4.30	3.43	4.89
Measured Absorbed Dose (μGy)	2.1	10.8	3.4	8.4	9.7	7.1	12.8
Average Measured Absorbed Dose Rate (μGy/hr)	1.5	2.9	1.7	2.5	2.3	2.1	2.6
Modeled Absorbed Dose (μGy)	3.8	14.1	5.9	12.1	14.3	11.7	18.2
Average Modeled Absorbed Dose Rate (μGy/hr)	2.8	3.7	3.0	3.7	3.3	3.4	3.7
Percent Difference	46	23	43	30	30	40	30

CARI-7A absorbed dose estimates are consistently higher than AirTED measurements, probably due to lack of sensitivity of AirTED to low LET radiation.

Solar Balloons to measure SSAIRE and SPE at 15-25 km altitude

Blue Origin New Shepard flight currently scheduled for 3rd quarter of 2023





Conclusions: AIRE Institute Current Projects

- NASA WB-57 ongoing flights:
  - deployed to Korea for summer 2022 campaign,
  - later will add AirSiD (and other detectors) to existing AirTED.
- Ground-based Cosmic Ray monitors (neutron, muon, x-ray).
- Herado AlmarAIR personal aviation dosimeter.
- Solar Balloon flights with AirSiD, then mini-AirTED
- AirTED experiment on Blue Origin New Shepard suborbital flight:
  - 3rd Quarter 2023,
  - dosimetry for space tourism.
- eATED experiment on ISS:
  - 6 months duration,
  - launch on SpaceX-28 in June 2023,
  - implement lessons learned from 2018 ISS experiment.

AIRE Institute Personnel

- Eric Benton (director), Oklahoma State University, Dept. of Physics
- Kyle Copeland, U.S. FAA, Civil Aerospace Medical Institute
- Brad “Buddy” Gersey, Founders Classical Academy

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- Conner Heffernan, OSU Physics Ph.D. student
- Garrett Thornton, OSU Physics undergraduate student

AIRE Institute Former Students

- Paul Inman, OSU Physics Ph.D. student (graduated 2021)
- Ryan Boyce, OSU Physics undergraduate student (graduated 2022)

AIRE Institute US Collaborators

- Stephen Wender, Los Alamos Neutron Science Center, DOE LANL
- Jack Miller, Lawrence Berkeley National Laboratory and NASA ARC
- Bryan Hayes, Space Radiation Analysis Group, NASA JSC (OSU graduate)
- Chris Mertens, NASA LaRC

AIRE Institute International Collaborators

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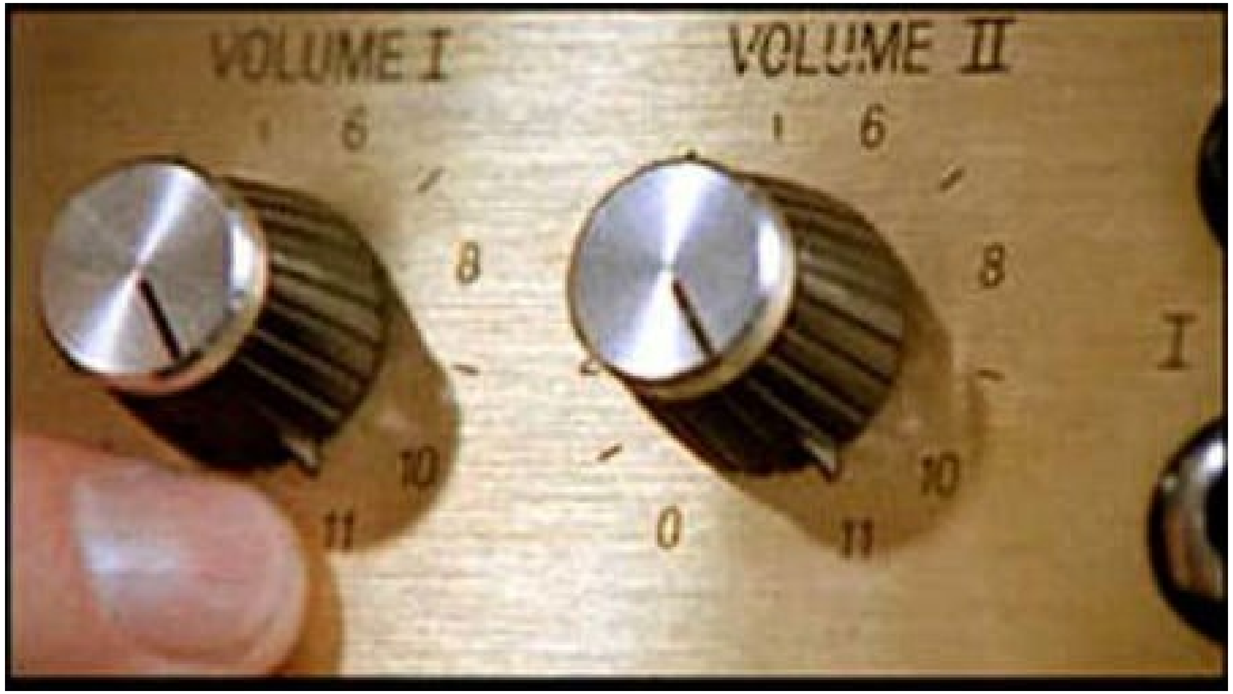
- Alex Hands, U of Surrey, UK
- Ondrej Ploc et al., NPI Czech Academy of Science, Czech Republic

eATED measures to H*(11)



Acknowledgements

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