OAK RIDGE National Laboratory

The Development of a Rugged Weather-Resistant Continuous Holdup Monitor for Ductwork at Nuclear Facilities

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Oak Ridge National Lab

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U.S. DEPARTMENT OF ENERGY

Impetus for a Distributed System

- Nuclear facilities process fuel in glove boxes with HEPA filtering
- Some escape of nuclear material from glove box into ductwork is unavoidable
- Current approach – yearly spot measurements
  - Hundreds of measurement points
  - Difficult to reach – hazards to personnel

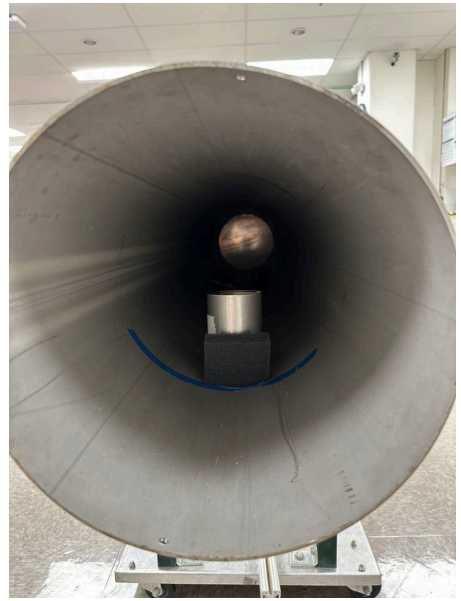
Key Challenges for Distributed Holdup Monitor

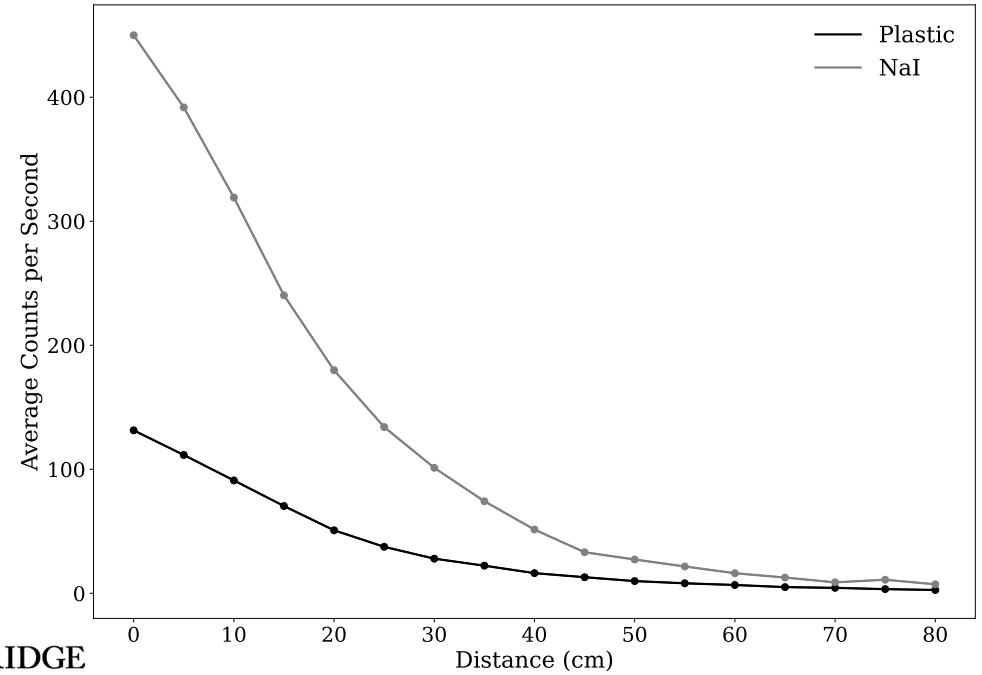
- Hundreds of monitoring points
- Varying environmental conditions (temp, humidity, etc.)
- Location access
- Data collection (e.g., wireless, wired, onboard recording)
- Power supply
- Maintenance and calibration (e.g., NQA-1 requirements)
- Price point – affordable
- Reduced cycle time

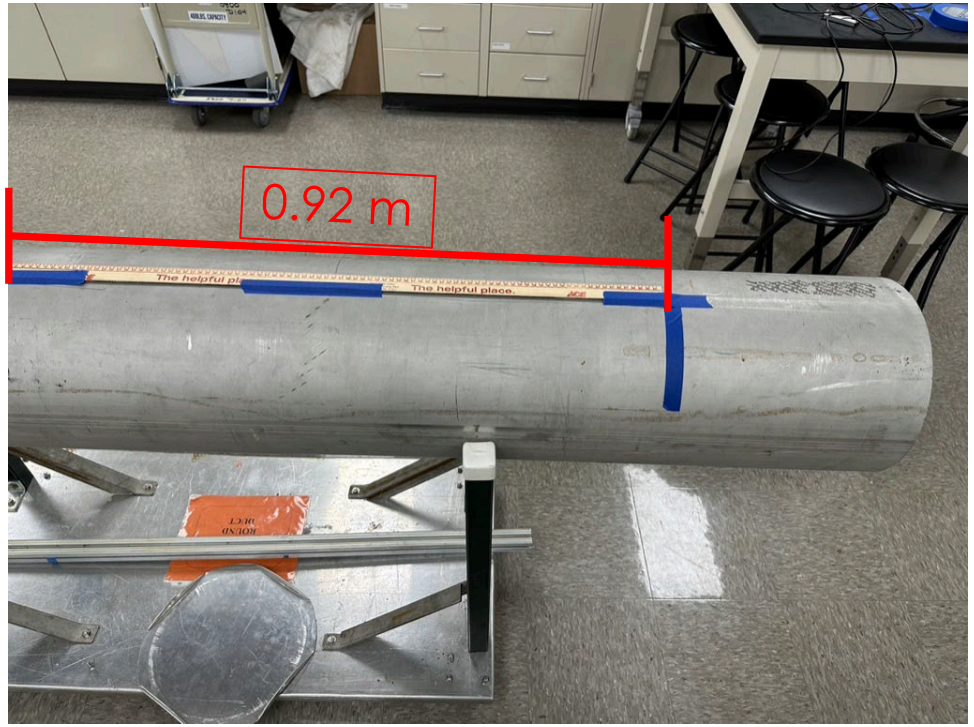
Benchtop Testing

Benchtop tests: simulated holdup test

- EJ200-NF plastic scintillator coupled in house PMT, NaI coupled to PMT by Saint Gobain, Rev0 counting electronics
- Source: 4.46% enriched Uranium
- Duct: 30 cm ID, 0.28 cm thick stainless steel
- 2-minute counts at 5 cm intervals

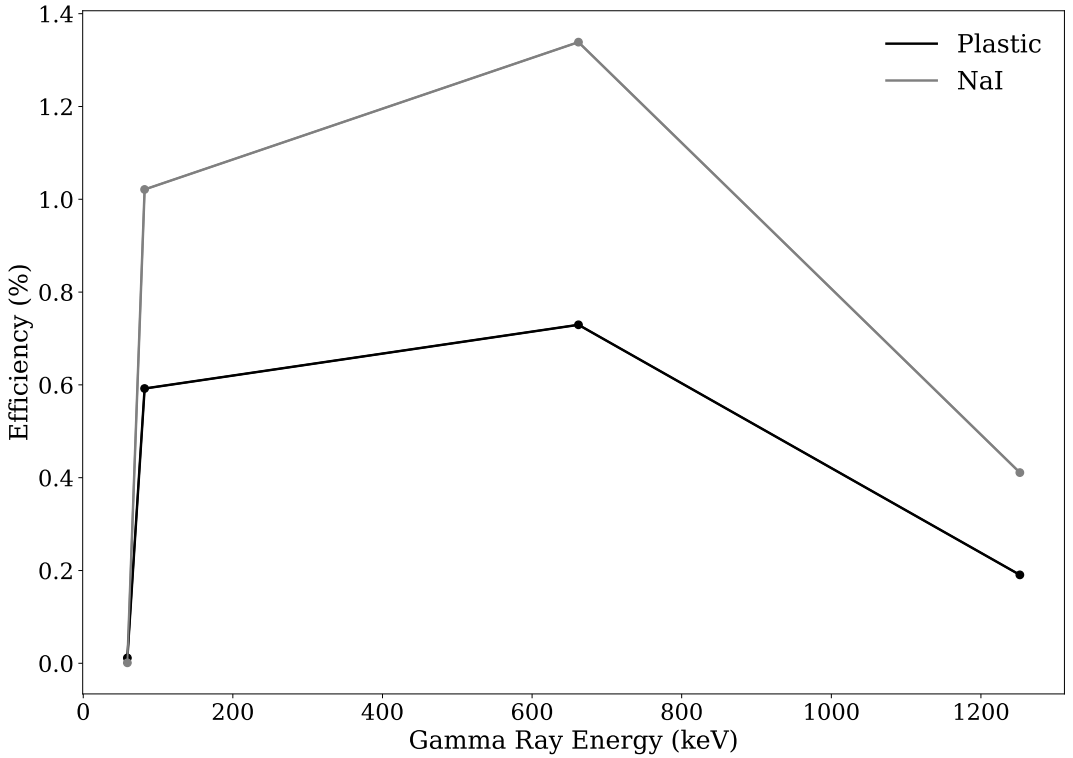






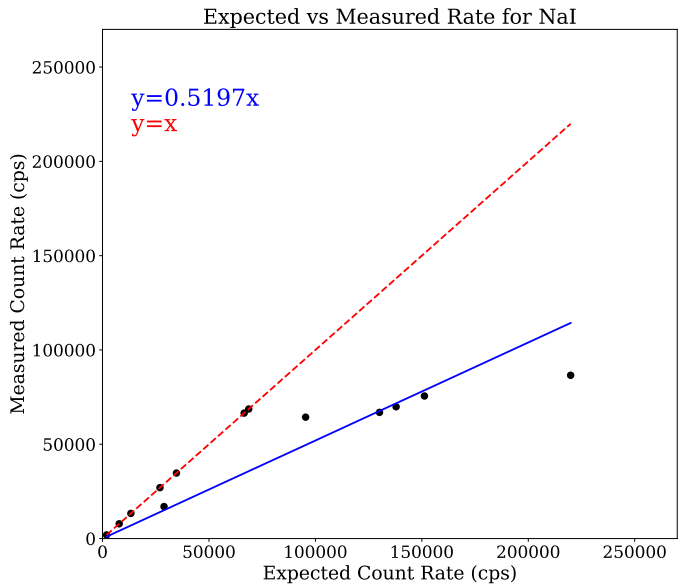
Benchtop tests: Energy-Dependent Efficiency

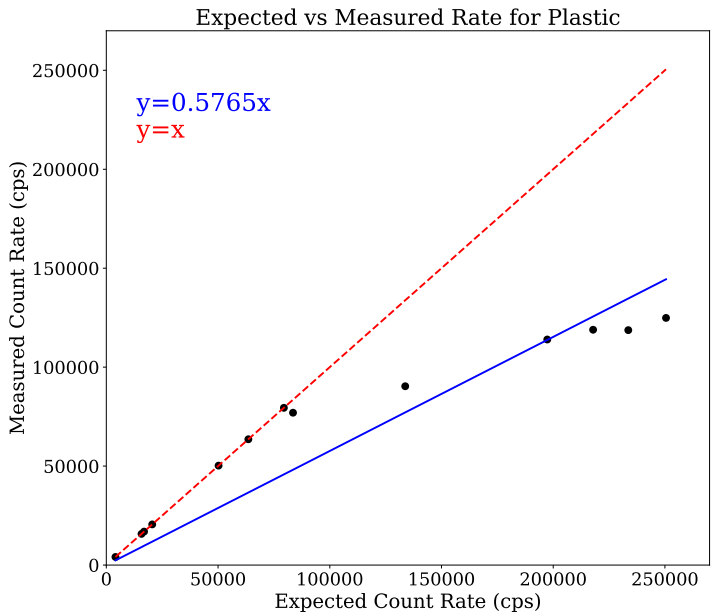
- EJ200-NF plastic scintillator coupled in house PMT, NaI coupled to PMT by Saint Gobain, Rev0 counting electronics
- Threshold tuned for 100 keV – 2 MeV detection range
- Shows typical behavior with low E threshold effects, loss in efficiency at higher energies,
- NaI more efficient than plastic (expected)
- Sources:
  - ^{241}Am: 56 keV
  - ^{133}Ba: 82 keV
  - ^{137}Cs: 662 keV
  - ^{60}Co: 1252 keV (average of 1173 and 1332 keV)
- Takeaway: sees ~100 keV well



Benchtop tests: Maximum Rate

- EJ200-NF plastic scintillator coupled in house PMT, NaI coupled to PMT by Saint Gobain, Rev0 counting electronics
- Measured for 2 minutes with range of sources individually in contact with detector, then two sources, etc
- Averaged CPS, expected count rates are addition of average CPS added together versus sources measured together
- Examining for linear threshold in rate
- Sources:
  - ^{133}Ba, ^{241}Am, ^{137}Cs, ^{152}Eu, ^{166}Ho, thorium lens
- Linear region ends around 100k counts, above desired alarm threshold?

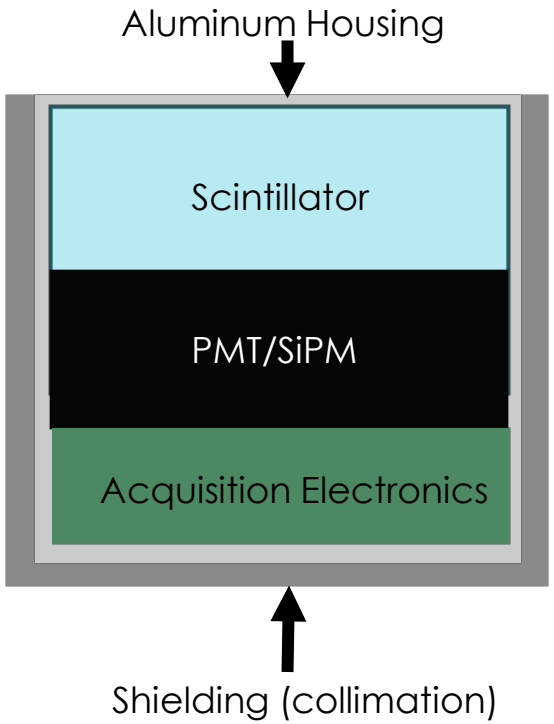


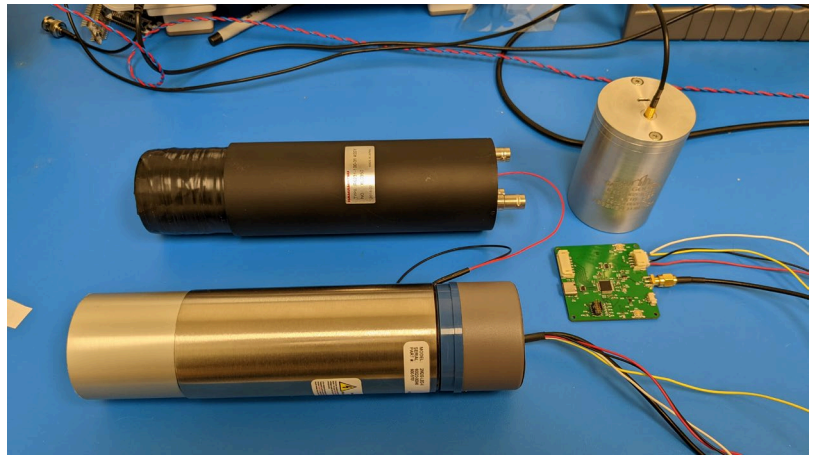


Prototype Detector

Base Detector Characteristics

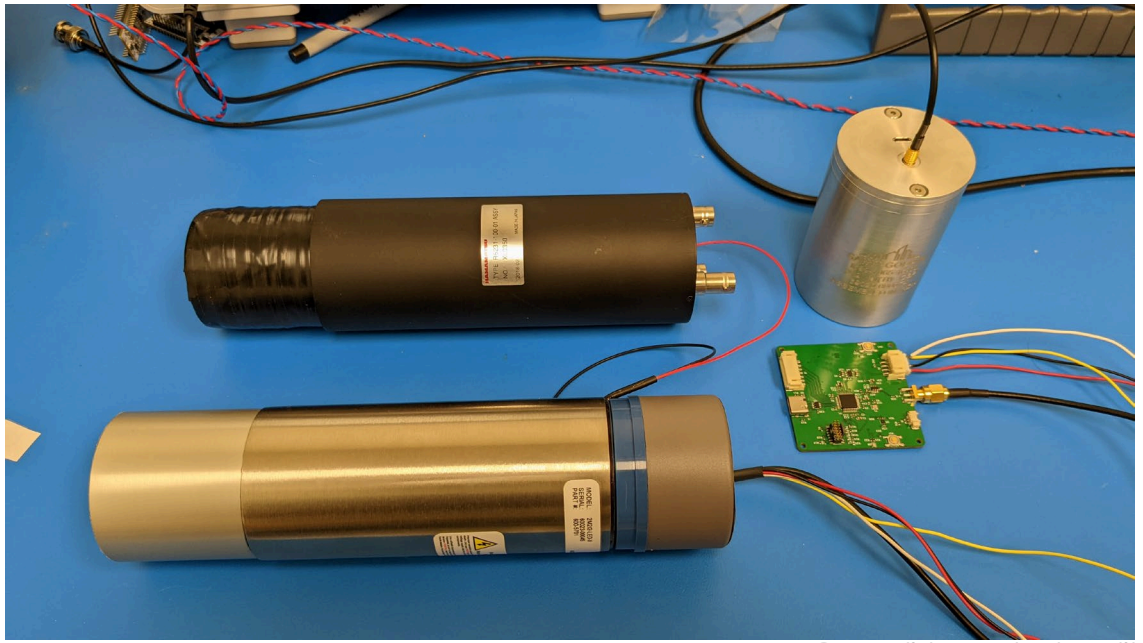
- Collimated and self-contained scintillation detector and acquisition
- Rugged design with temperature compensation for long-term indoor or outdoor usage
- Use off-the-shelf components where possible with custom acquisition hardware to minimize price and system size
- Communication scheme and scintillator dependent on use cases – Power over ethernet or battery powered
- Integrated LED and source for system health checks





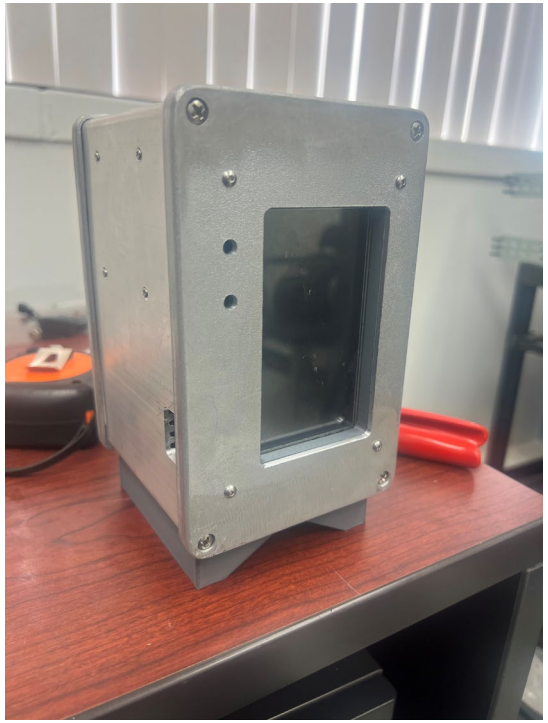
Industry Comparison

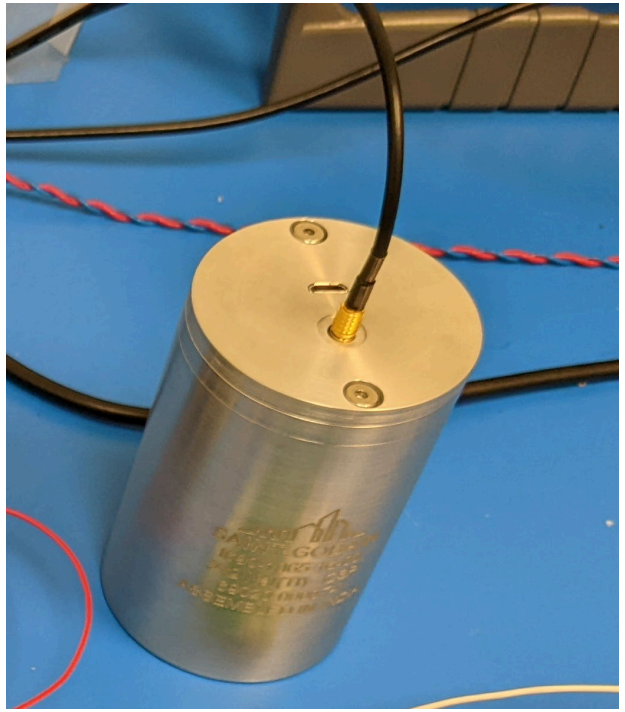
- Mirion CsI (SIGMA) detectors: ~$10k/unit
  - Designed as desktop unit
  - Paying extra for unnecessary equipment (MCA)
- MPACT Holdup - <$1k per unit, estimate ~$500-600/unit at hundreds of units
  - Custom designed for rugged, outdoor use
  - Designed for many detectors to work together
  - No unnecessary electronics (only counting)



Field-able Prototype

- Field-able NaI + SiPM from Saint Gobain
- Requires outer housing for electronics, detector, and collimator
- ¼" Tungsten grit collimator - 50% reduction of ^{238}U gamma rays





Driving to lower costs (intent for next phase)

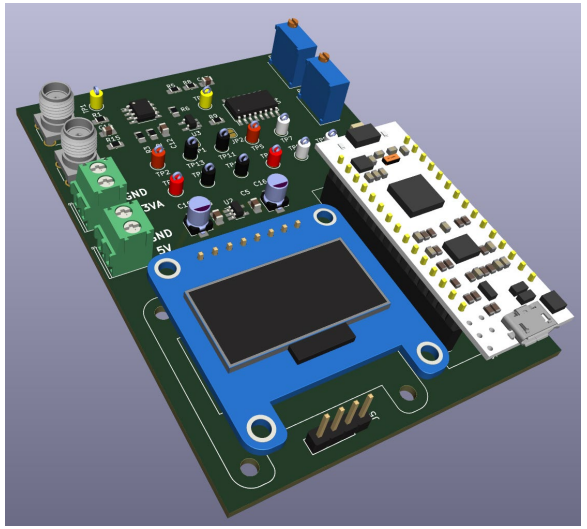
- Demonstrate feasibility of plastic & SIPM design
- Current EJ200-NF 2 inch cylinders are ~ $50 each in volume
- SIPM integration needs to be demonstrated – current arrays range from $144 to $825 depending on size of array
- Standardized electronics for different configurations
- Correlate new design with current systems using actual field data

Prototype Hardware

Prototype Acquisition: Rev0 and Rev1

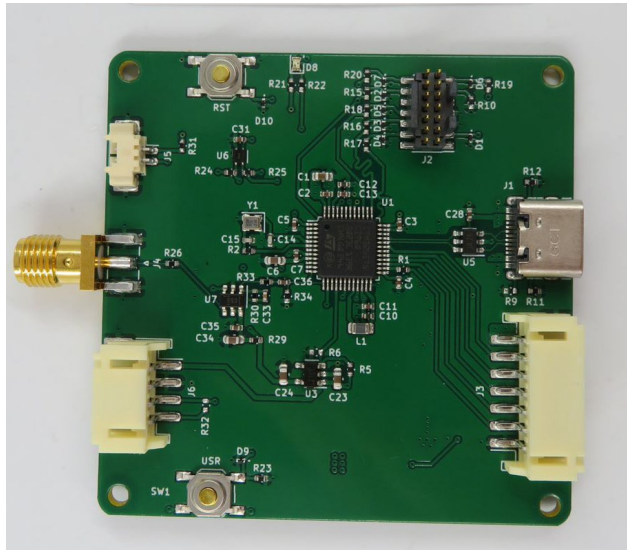
Rev0

- Early prototype board - PMT assembly only
- Communication/power over USB
- Discriminator using comparator, ADC on microcontroller for counting
- Potentiometer for threshold adjustment
- CPS reported via onboard screen or via USB
- Counting period settable in software



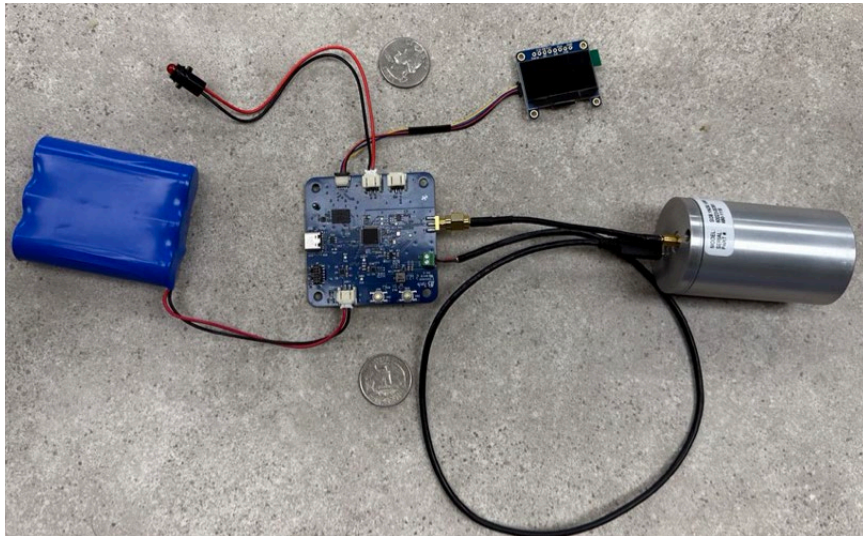
Rev1

- PMT assembly only
- Power over ethernet
- Discriminator using comparator, ADC on microcontroller for counting
- Threshold, counting period, and PMT voltage settable in software



Prototype Acquisition: Rev2+

- PMT + SiPM integration with charge-sensitive preamplifier
- Onboard screen – count rate, red/yellow/green
- Threshold, counting period settable via software
- Temperature compensation



Hub Model

- Communications and power over ethernet
- Constantly communicating with hub
- Operates as distributed monitor coordinated by hub

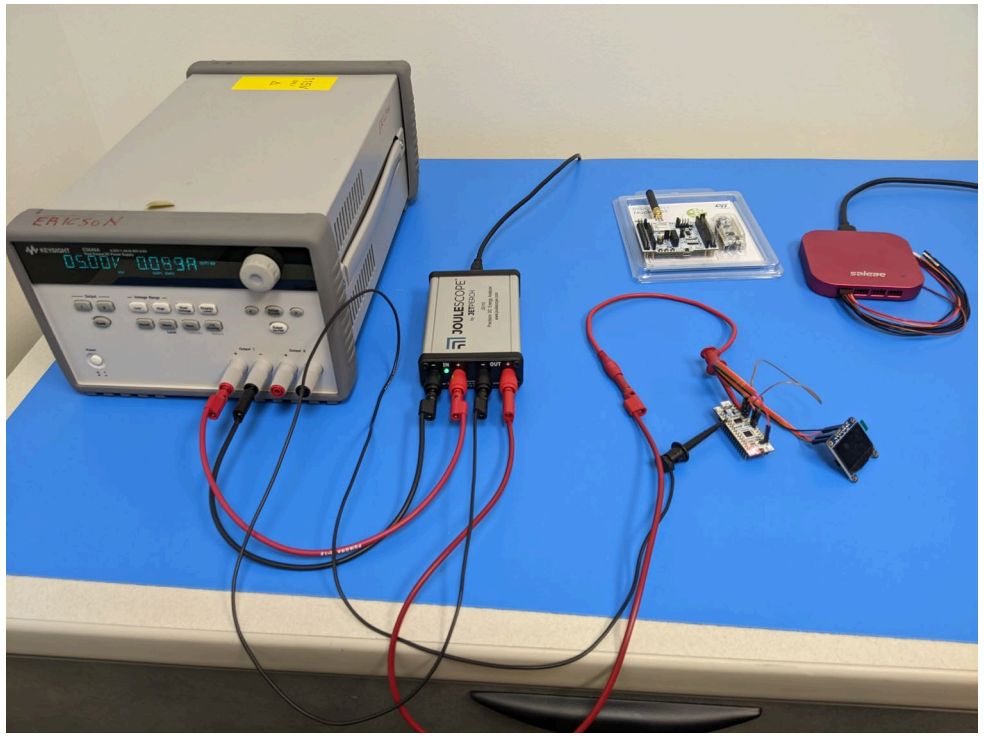
Battery Model

- Battey powered – last for weeks
- Solar Power harvesting for extended battery life
- Onboard non removable memory
- Charging/communication via USB
- Communication/power over USB

Prototype Software/Algorithms

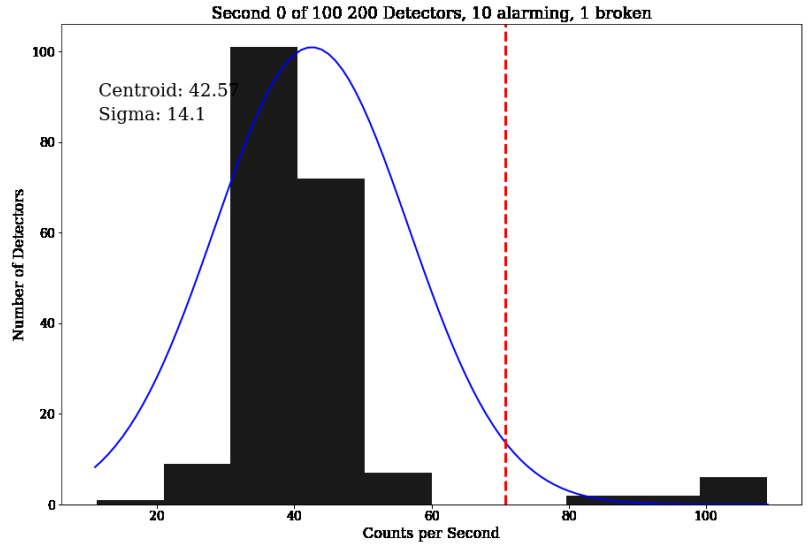
Software Kit Development

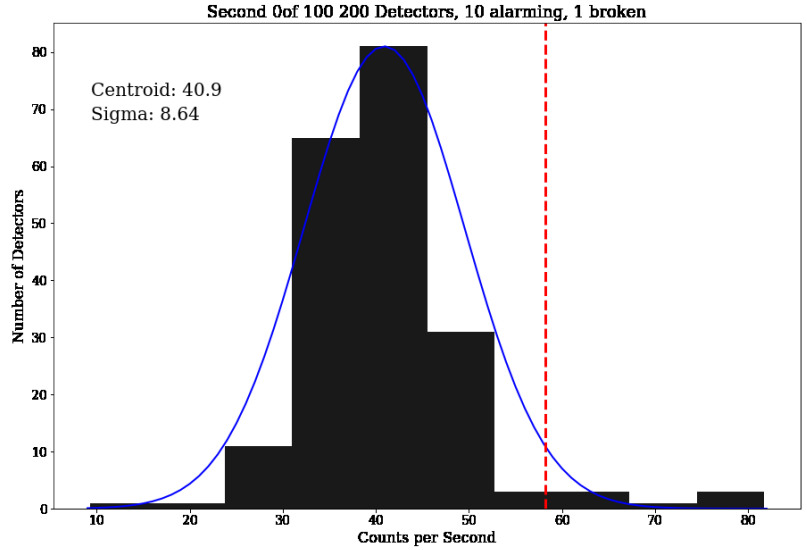
- Scalable Zephyr RTOS based software development kit (SDK)
- Early power measurements of digital components
- SDK usable for eventual system integration



Alarming Algorithm

- Principle of Algorithm:
  - Each individual detector is both background and detector
  - All detectors in group count for set period, report back
  - Average CPS taken for all detectors fit with normal distribution
  - Alarm for individual counting period is 2 sigma off normal
  - Detector officially alarms as or is identified as broken after some set number of counting periods
- Strengths:
  - Allows for time-variable background in between counting periods
  - Can automatically detect alarming/broken detectors
- Assumptions:
  - Similar background between all detectors in group during counting period (i.e. elevated rate is real)
  - Most detectors are working
  - Large number of detectors in group
- Work ongoing to identify limits





Conclusion and Lookahead

- Benchtop tests of in-house prototypes with Rev0 counting electronics
- Rev1 electronics in house, Rev2 en route, Rev3 underway
- First fieldable prototype detector housing in house
- Alarming algorithm development underway
- Field-able SiPM-based detector with Rev2 electronics will undergo field tests later this FY

Questions?