

# Design of a Dual-Detector Gamma Spectrometer for In Situ Marine Radioactivity Monitoring

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## Abstract

Real-time in-situ  $\gamma$ -ray monitoring is required for coastal nuclear surveillance and emergency response. This work presents a buoy-mounted dual-detector  $\gamma$  spectrometer combining CZT for radionuclide identification and CsI(Tl) for dose-rate monitoring, supported by FPGA-based readout electronics. Laboratory tests and an 88 h field deployment in Weihai demonstrated stable operation, a CZT energy resolution of 2.28% at 662 keV, and a CsI(Tl)-based dose-rate measurement of 2.81–3.23 nGy·h<sup>-1</sup>. Observable spectral features attributable to <sup>40</sup>K and uranium/thorium-series products were also recorded.

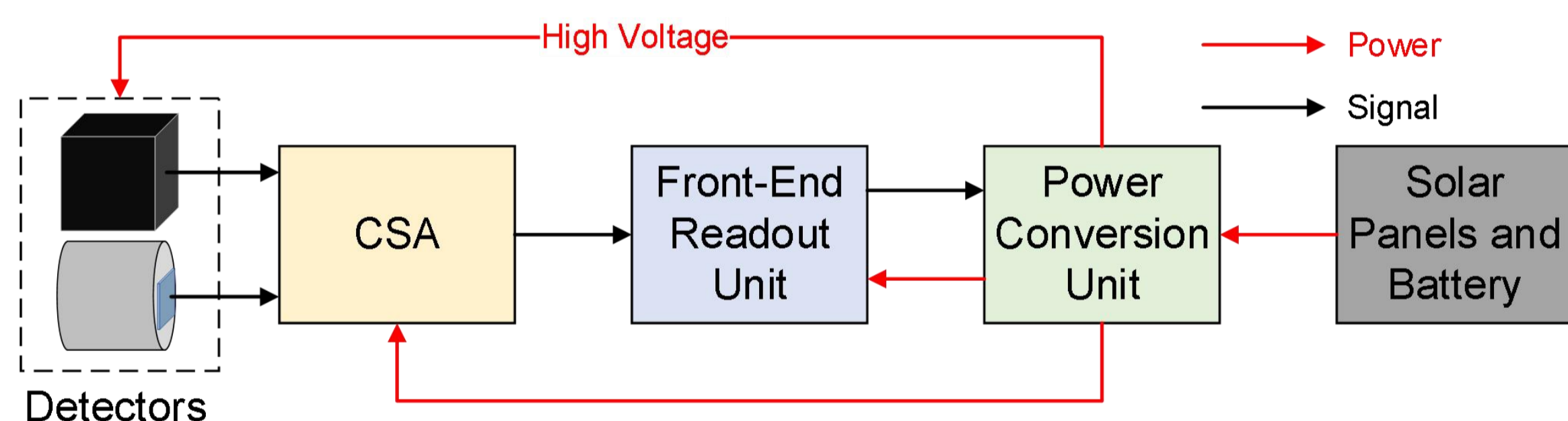
## Introduction

- **Monitoring Demand:** Real-time in-situ marine  $\gamma$ -ray monitoring is required for routine surveillance and emergency response near coastal nuclear facilities.
- **Sampling Limitation:** Offshore sampling followed by laboratory analysis provides high accuracy but suffers from time delay.
- **Detector Trade-off:** A dual-detector design combines CZT resolution and CsI(Tl) efficiency for simultaneous radionuclide identification and dose-rate monitoring.

## System Design & Readout Electronics

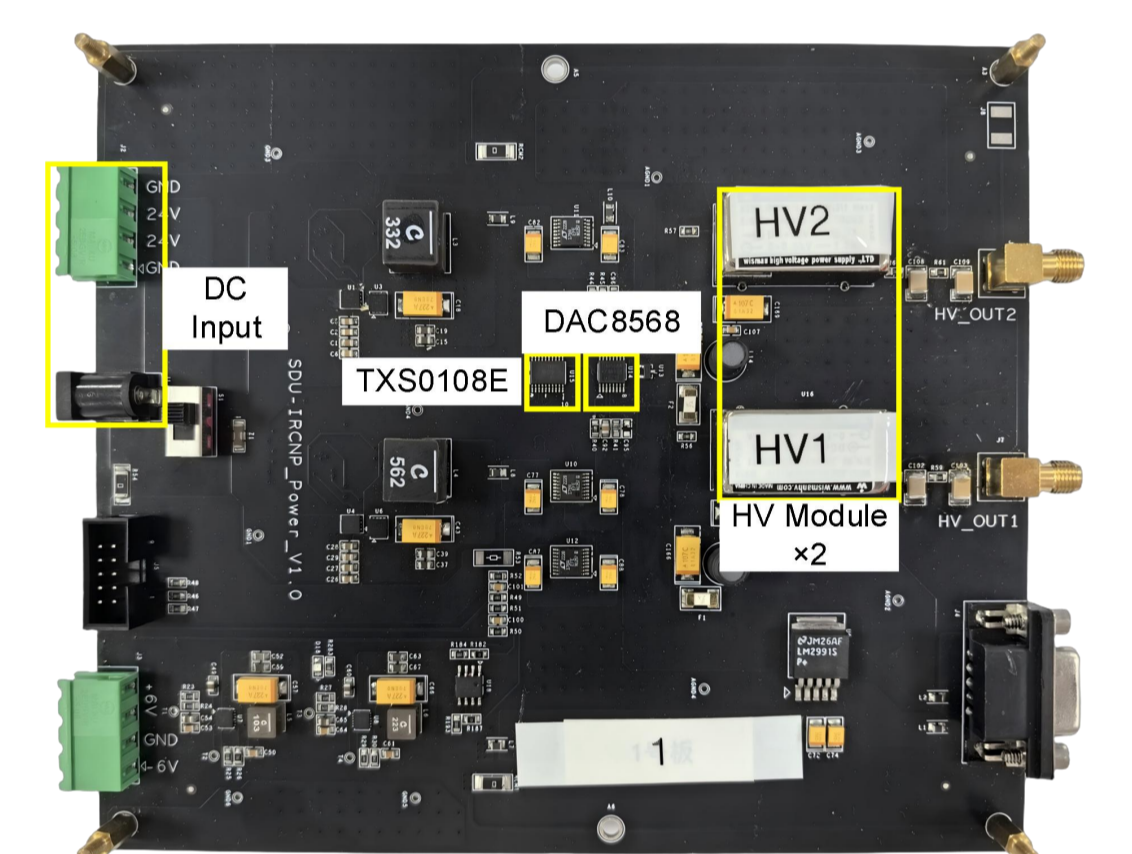
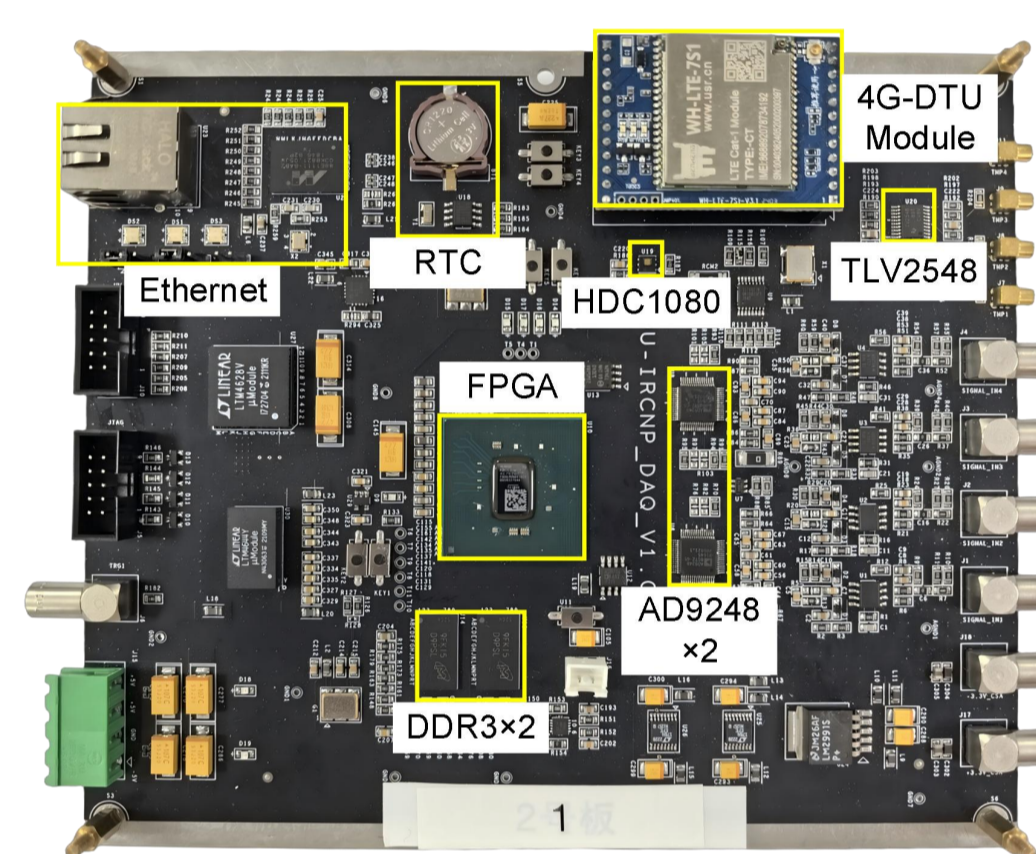
### System Architecture

- **System Composition:** Buoy platform, waterproof housing, solar power, PCU, FRU, CSAs and dual-detector unit.
- **Deployment:** Solar-powered buoy with the detector unit installed approximately 1 m underwater.
- **CZT Detector:** 10 × 10 × 10 mm<sup>3</sup> CZT for high-resolution radionuclide identification.
- **CsI(Tl) Detector:**  $\Phi$ 30 mm × 30 mm CsI(Tl) for high-efficiency dose-rate monitoring.
- **Dose Conversion:** CsI(Tl) spectra are converted to dose rate using the G(E) function in the DAQ system.

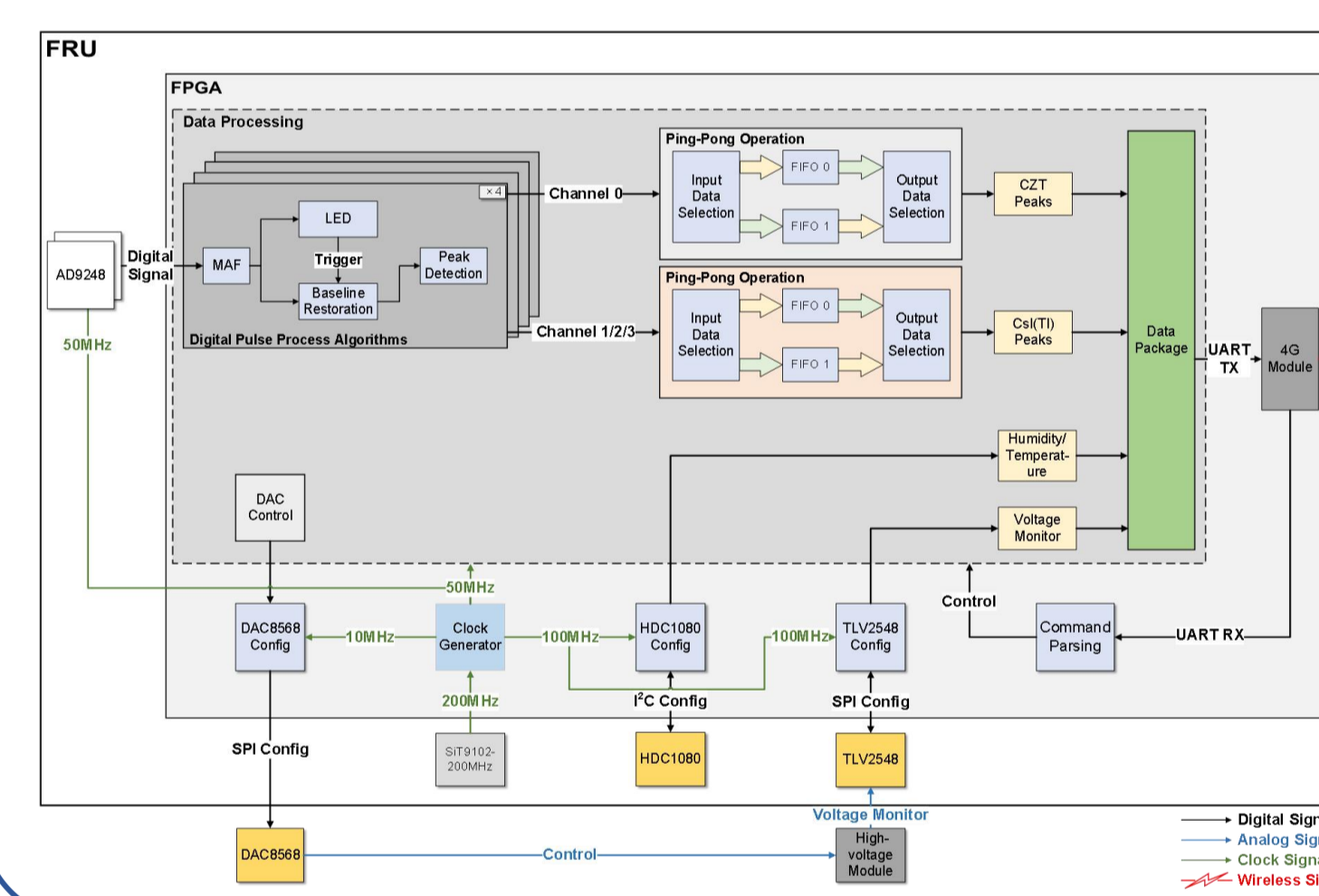


### Hardware Architecture

- **FRU:** 4-channel input, 14-bit ADCs, Kintex-7 FPGA and 4G/Ethernet communication.
- **PCU:** Converts +24 V battery power to stable system supplies and controlled detector bias.



### FPGA Firmware Logic



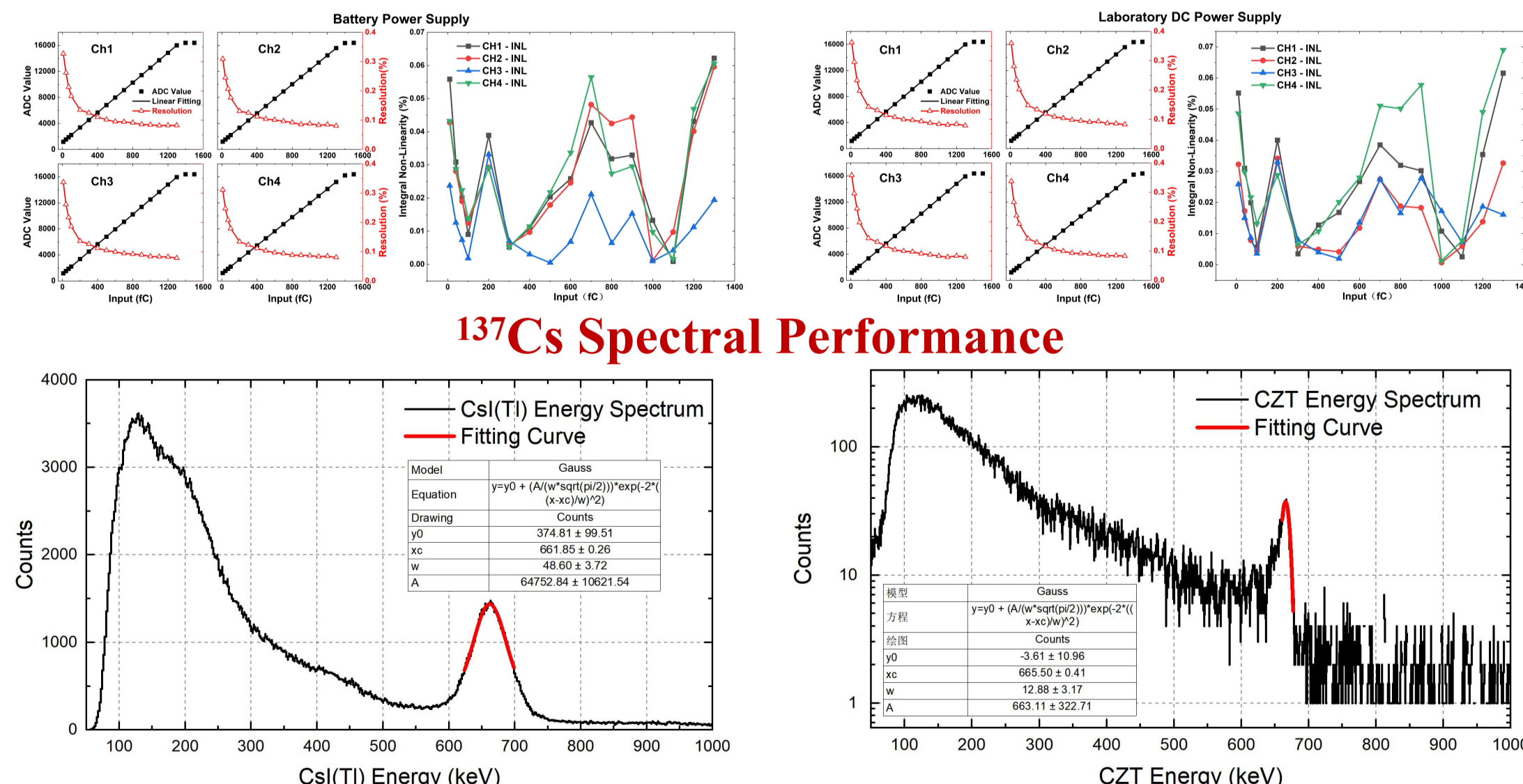
- **DPP:** MAF → baseline restoration → trigger → peak extraction.
- **Buffering:** FIFO ping-pong for continuous acquisition and upload.
- **Control:** Remote DAQ control of acquisition, status, 4G and bias.

## Performance Measurement & Field Test

### Laboratory Performance

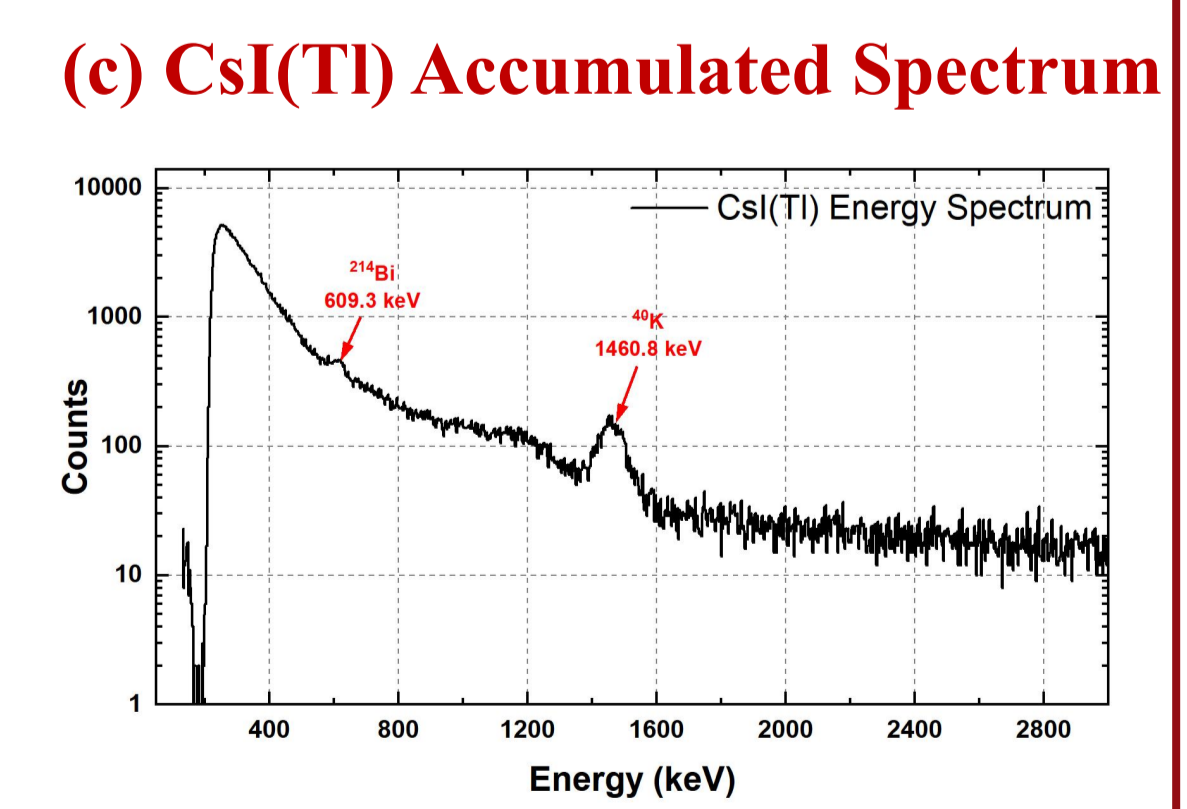
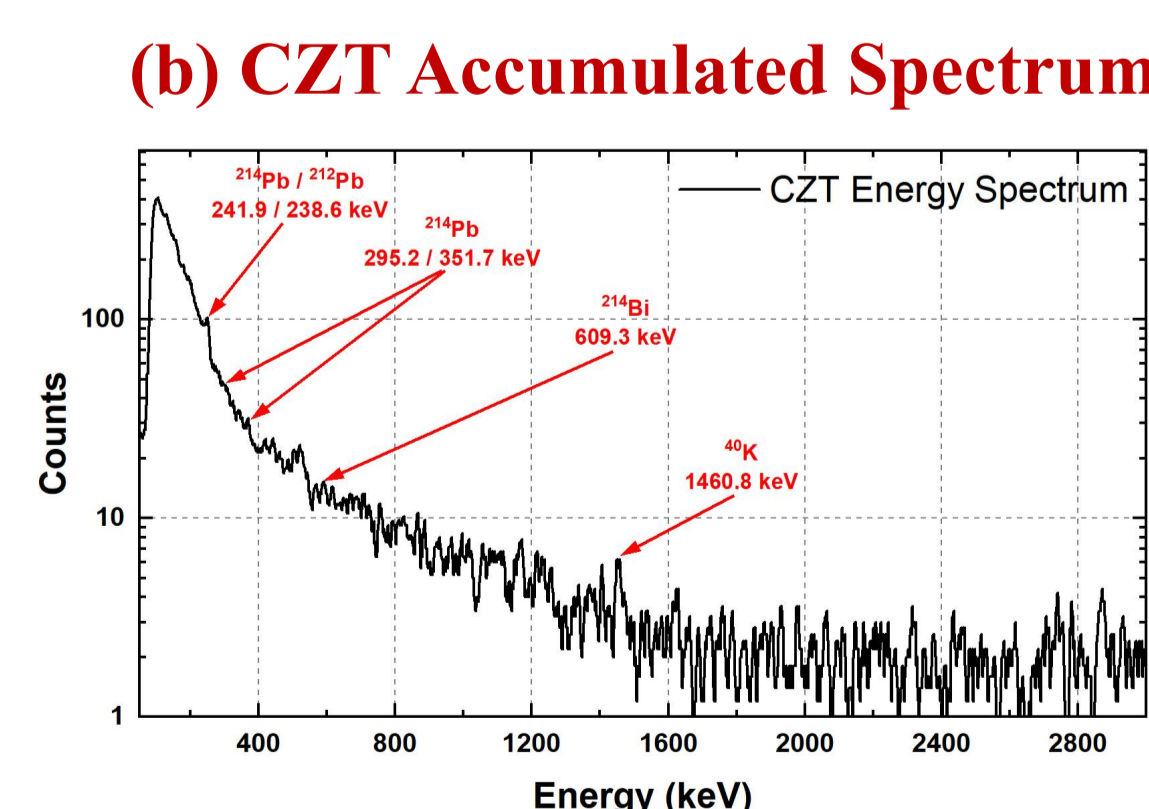
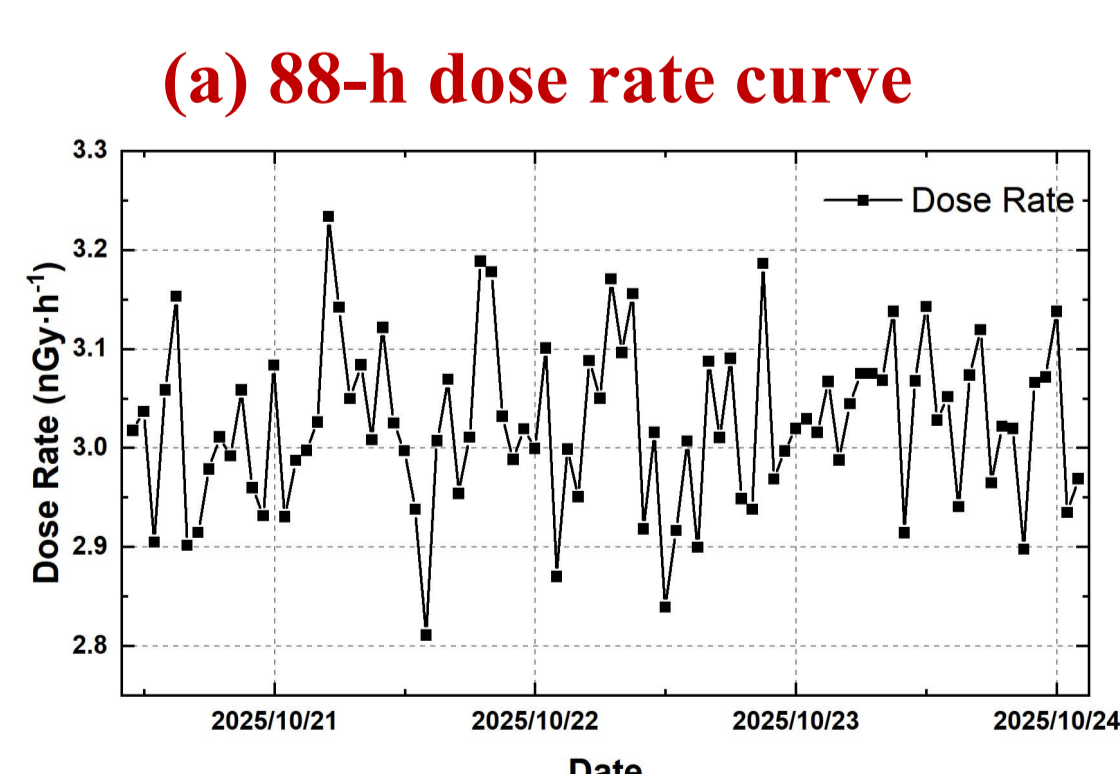
- RMS noise < 2.75 ADC codes with CSA connected.
- Linearity:  $R^2 > 0.9999$ ;  $INL \leq 0.062\%$  under battery power.
- Amplitude resolution < 0.362% at 10 fC.
- <sup>137</sup>Cs energy resolution: CZT 2.28% at 662 keV; CsI(Tl) 8.65% at 662 keV.

#### Linearity, Resolution & INL



### Field Deployment Validation

- Location: Nearshore waters of Weihai, Shandong, China.
- Duration: Continuous operation for approximately 88 h.
- Dose Rate: 2.81–3.23 nGy·h<sup>-1</sup>.
- Observed Radionuclides: <sup>40</sup>K, <sup>214</sup>Bi and <sup>214</sup>Pb / <sup>212</sup>Pb.
- Environmental Stability: Humidity < 39%; detector temperature 18.99–20.52 °C.



## Conclusion

- A buoy-mounted dual-detector  $\gamma$  spectrometer was developed for in-situ marine radioactivity monitoring.
- CZT and CsI(Tl) provide complementary capabilities for radionuclide identification and dose-rate monitoring.
- Laboratory tests and an 88 h Weihai deployment verified stable unattended operation in a real marine environment.

## Acknowledgments

- This work was supported by the Key R&D Program of Shandong Province, China under Grant 2023SFGC0101.