Status of ISS-RAD

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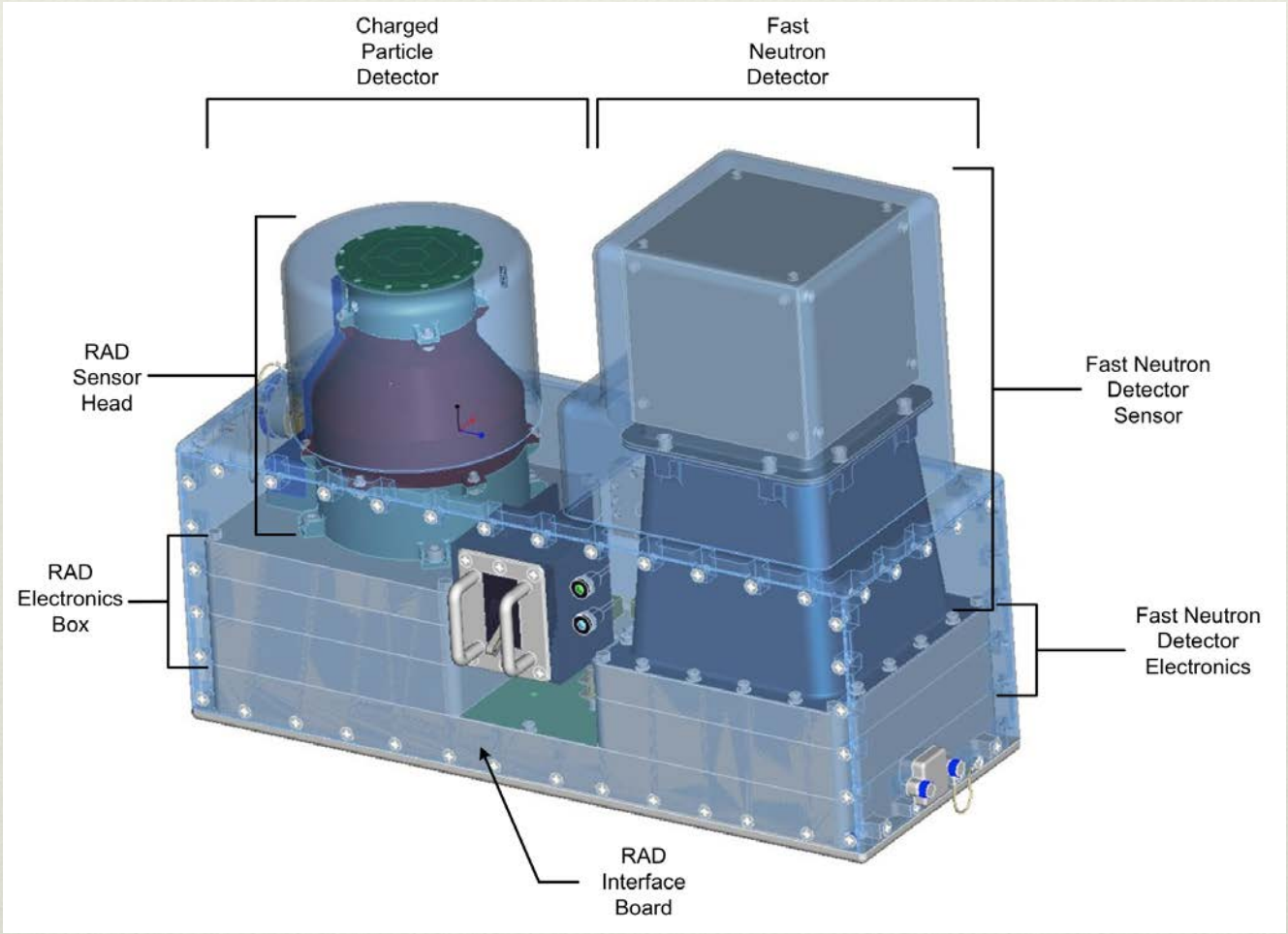
On behalf of the ISS-RAD Team

ISS-RAD ≈ MSL-RAD + FND

- Add Fast Neutron Detector (FND) to RAD.
  - Measure neutrons 0.5 – 8 MeV
- Many design changes.
- Name change: MSL-RAD-like part is now called CPD (Charged Particle Detector).
- 2 instruments in one package with shared interface.

A Thing of Beauty



FND: Capture Gated Neutrons

- Double pulse signature.
- Pulse 1: sum of recoil proton light flashes from thermalizing (avg. # recoil protons ~ 10).
- Pulse 2: thermalized neutron captured by $^{10}B \rightarrow {}^{4}He + {}^{7}Li + \gamma$
  - Δt distribution exponential, $<t> \sim 1.5\ \mu s$.
  - Capture pulse amplitude is in narrow range.
- 1st pulse amplitude related to incident neutron energy.
- Capture probability strongly energy dependent.

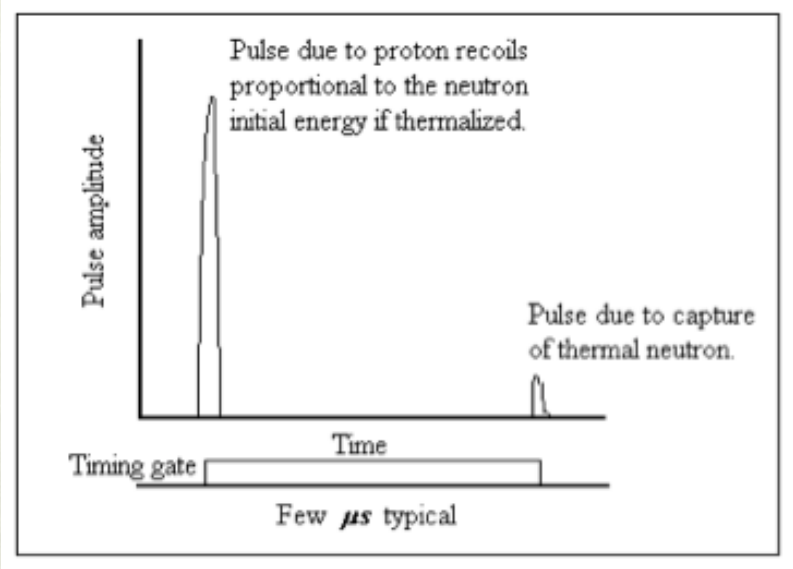
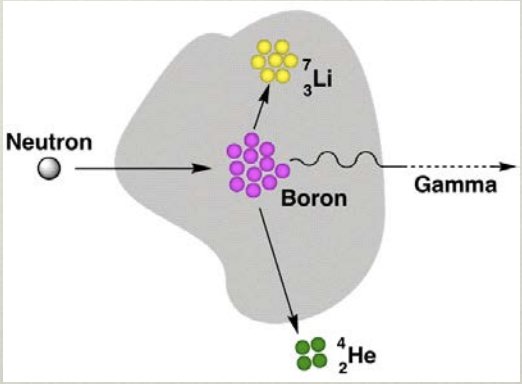
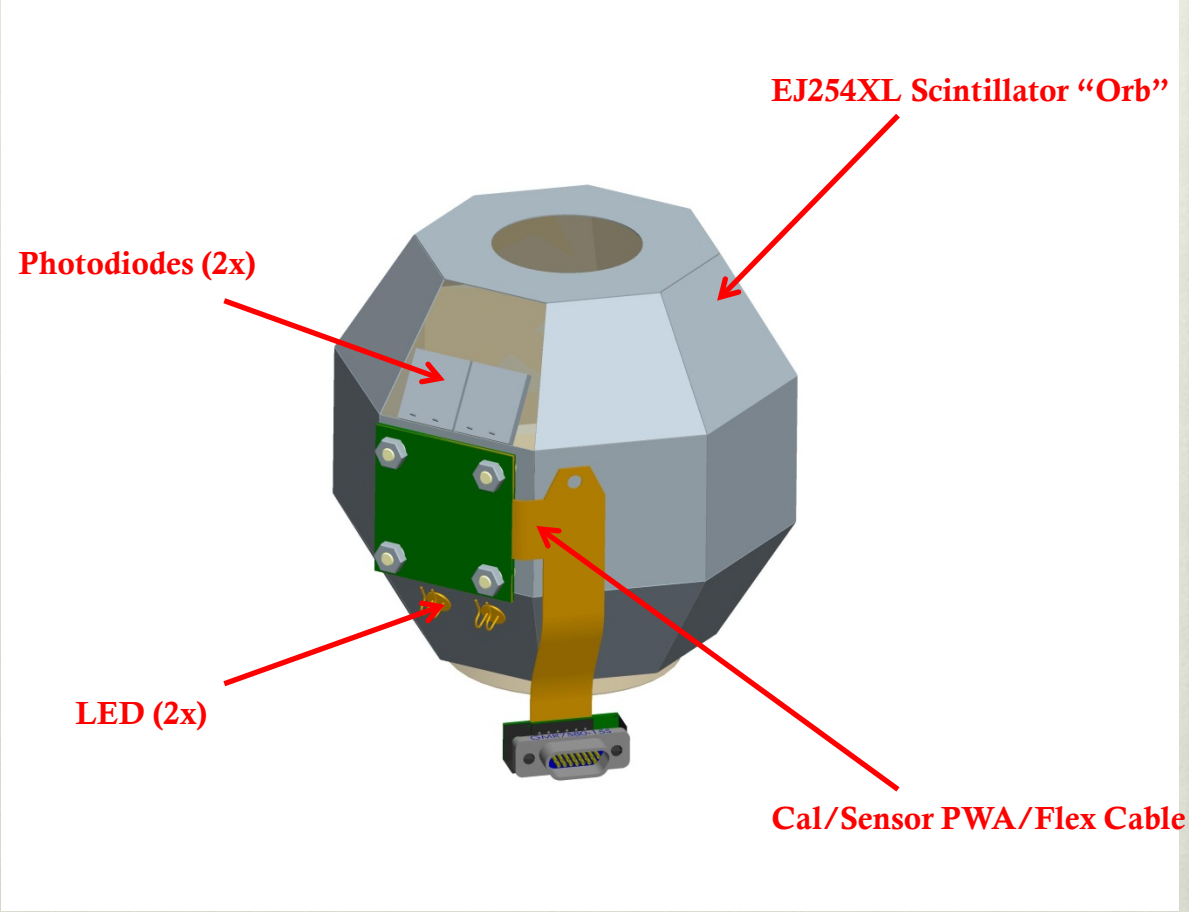


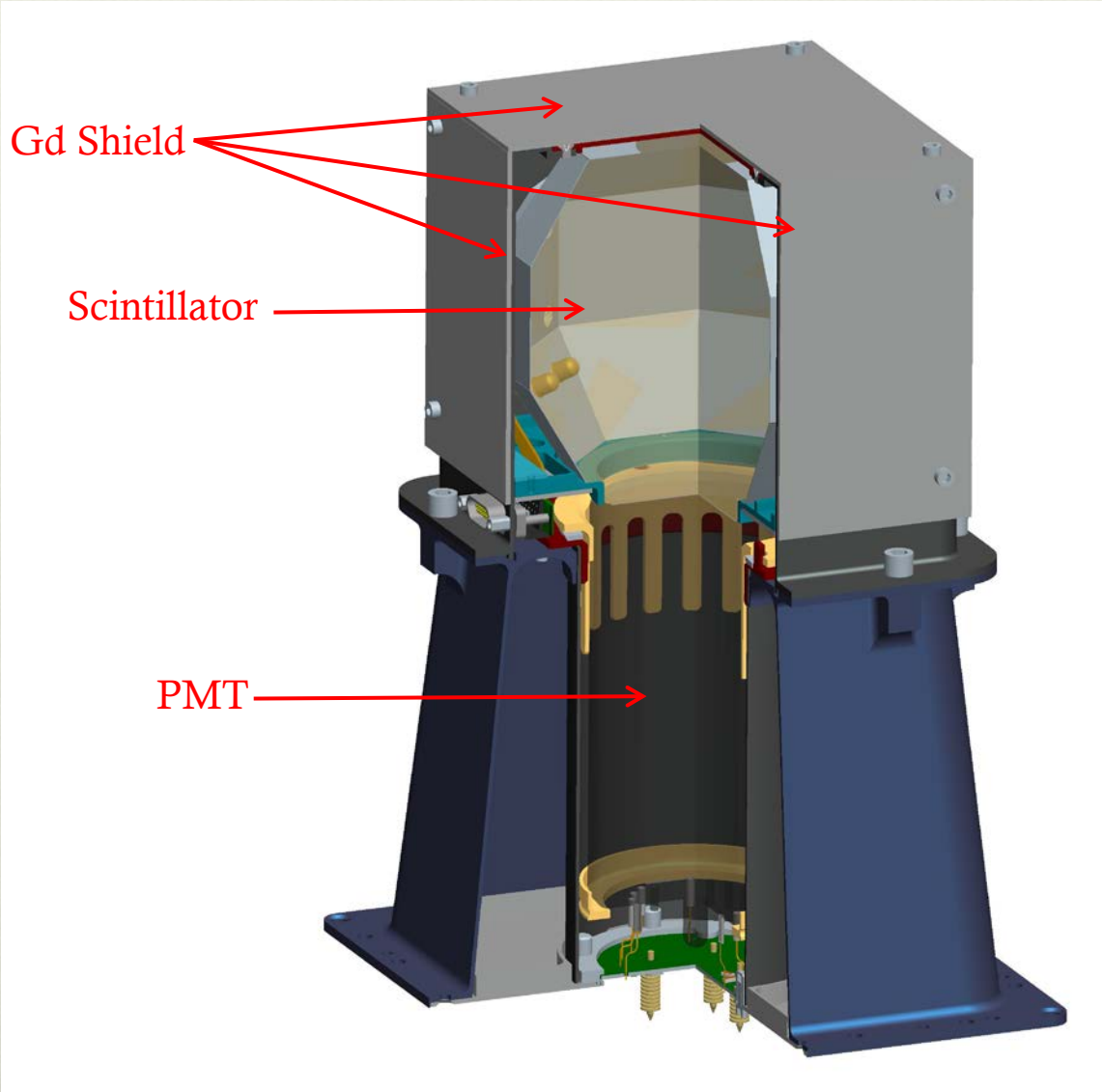
Figure from Sellin et al.



FND Scintillator Orb with Calibration LEDs and Diodes



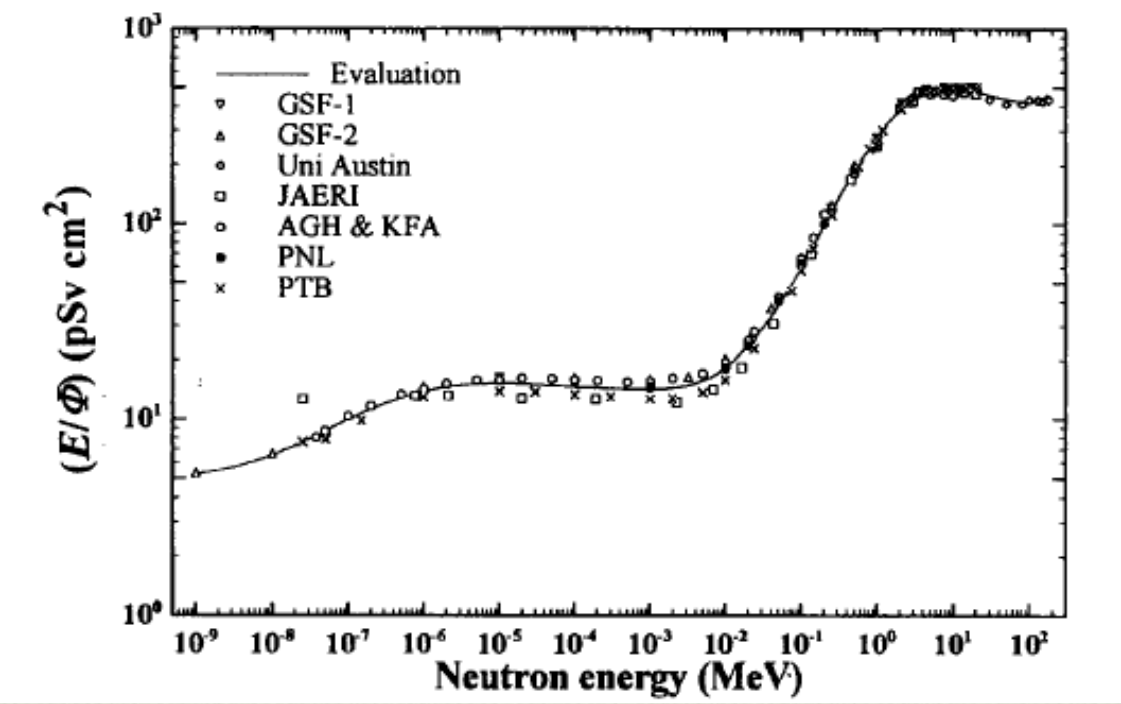
FND Sensor Design



FND Signal Processing

- Current from PMT base → transimpedance amplifier → shaping amplifier → fast ADC → FPGA.
- FPGA logic looks for pulse pairs.
- If 2nd pulse within time & amplitude windows, it might be a neutron.
  - Record amplitudes of 1st & 2nd pulses, Δt between pulses, absolute time.
  - Gating provides strong (not 100%) discrimination against γ's and charged particles.

Region of Interest



- ICRP74 neutron fluence to effective dose conversion.

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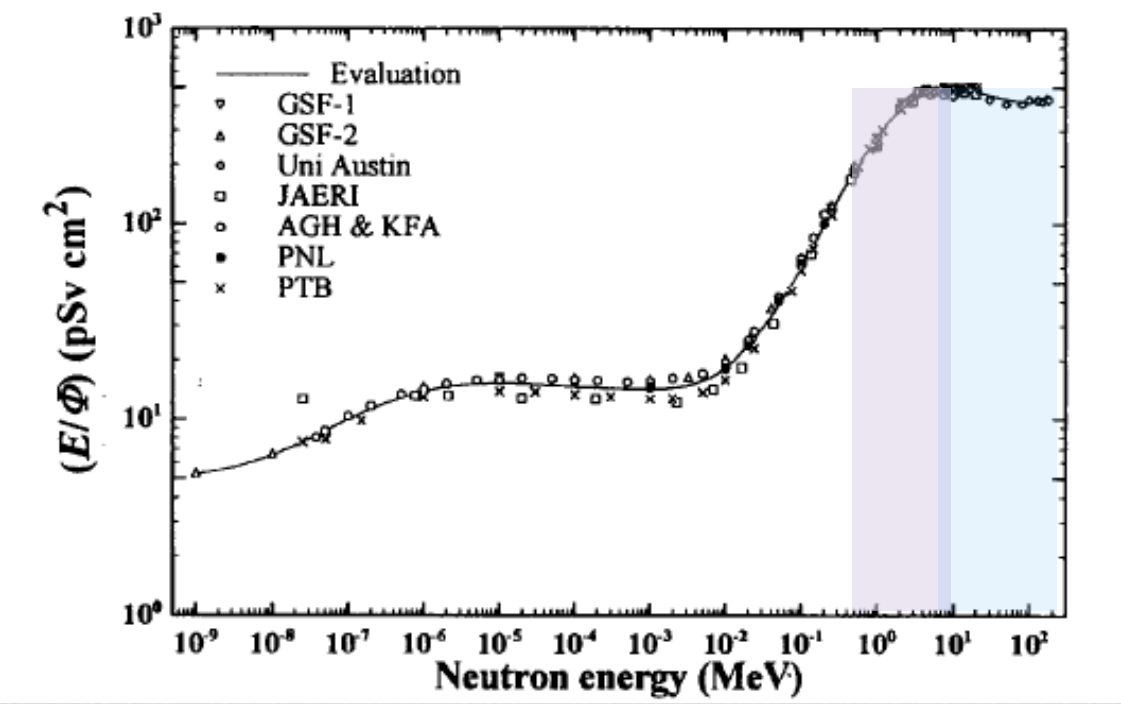
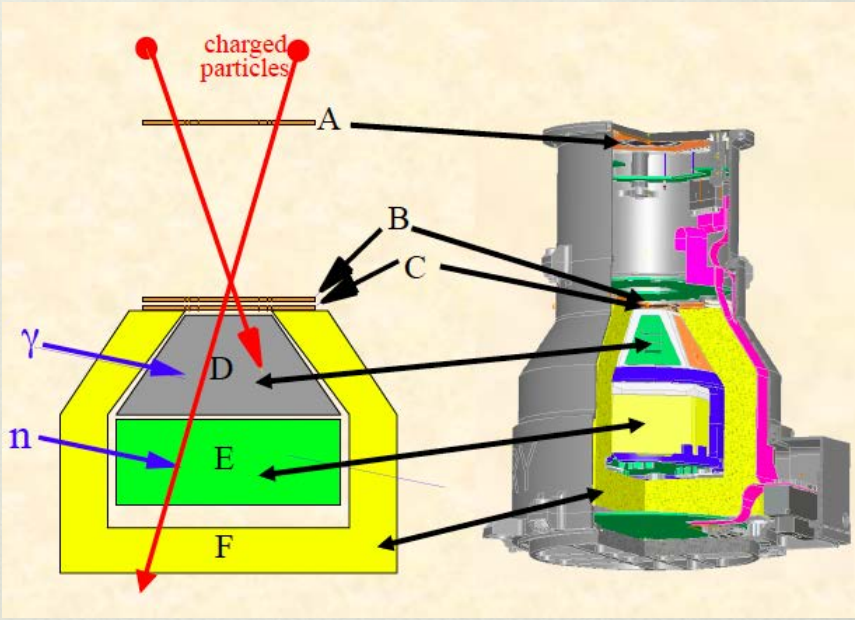


- ICRP74 neutron fluence to effective dose conversion.

CPD ≈ MSL-RAD

- Humidity: CsI(Tl) → BGO.
- BGO peak emission λ = 480 nm (green), CsI λ = 540 nm (orange).
  - Needed green-sensitive diodes so use green-emitting plastic for E & F scintillators.
    - EJ-260, brighter than BC-432.
    - BGO light output small compared to CsI(Tl).
- F was 1.2 cm thick, now 1.8 cm.
- F1 (upper) and F2 (lower) are optically coupled in MSL-RAD; decoupled for ISS-RAD.



RAD Interface Board (RIB)

- RIB functions:
  - Talks to both instruments.
  - Talks to Station via 1553, to laptop via USB.
  - Handles many different packet types.
  - Provides power to instruments from 28V or 120V.
- System has 4 FPGA's (2 CPD, 1 FND, 1 RIB)
  - 2 8051 microcontroller cores (CPD, RIB).
  - 6 processors to program & make work together (3 legacy).
- Lots of debugging needed.

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- Lots of debugging needed. **~35 data packet types flow in.**

Operations Concepts

- MSL-RAD operations based on "observation" of a specified duration, typically 16 minutes.
  - During observation, onboard code fills histograms, compresses & stores selected pulse-height event records.
  - At end, histograms and events are stored to NVRAM.
  - Observation stops, RAD sleeps for a specified time (30 seconds), wakes up, starts new observation.
  - Curiosity's main computer queries RAD a few times per day, retrieves observation data, telemeters it.
- ISS-RAD: always on, provides many data products on a 1-minute cadence.
- Telemetry volume → few PHA records from CPD.

Data Products

- Cyclic (1 minute, on ISS 1553 bus):
  - B dose rate, E dose rate
  - B dose equivalent rate (→ <Q> from LET spectrum)
  - FND dose equivalent rate (crude).
  - Cumulative doses & dose equivalents.
  - Differential proton flux in 3 bands: 20-34 MeV; 35-71 MeV; 72-122 MeV.
- Ground Analysis Software (GAS) produces another set of DP's:
  - More accurate neutron dose equivalent from FND.
  - Neutron absorbed dose from FND.
  - Neutron dose from CPD (E > 5 MeV) using s/w from J. Köhler.
  - Fluxes of low-energy heavy ions.

Configuration

- Two tables determine CPD configuration (~ 500 adjustable parameters).
- FND has a few parameters (HV, windowing cuts).
- RIB firmware uses a few additional Look-Up Tables.

ISS-RAD FM Calibration

- Flight Model Tour:
  - PTB, Braunschweig, May.
  - NSRL, Brookhaven, NY, April & June.
  - IUCF, Indiana University Cyclotron, IU, August.
  - AmBe testing at JSC.
- At PTB, discovered bad optical joint between FND orb and PMT → replace with spare, re-test @ PTB in Oct.

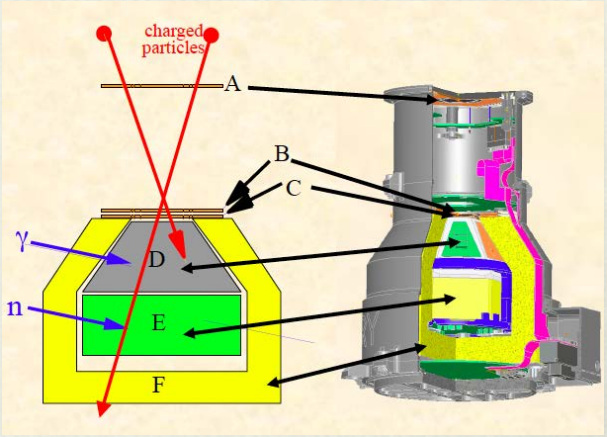
Calibration & Requirements Verification

- Neutrons @ PTB from 250 keV to 14.8 MeV.
- Protons @ NSRL and IUCF, 30 MeV to 1 GeV.
- Heavy ions @ NSRL (He, C, Si, Fe) at energies from ~ 100 to 1000 MeV/nuc.
- Challenging to make B and E dose rates ~ equal in beam run.
  - B area = 1.9 cm^2, E area ≈ 19 cm^2, want same fluence on both (large, uniform beam) while keeping total rate low to avoid deadtime (~ 500 μsec between events).

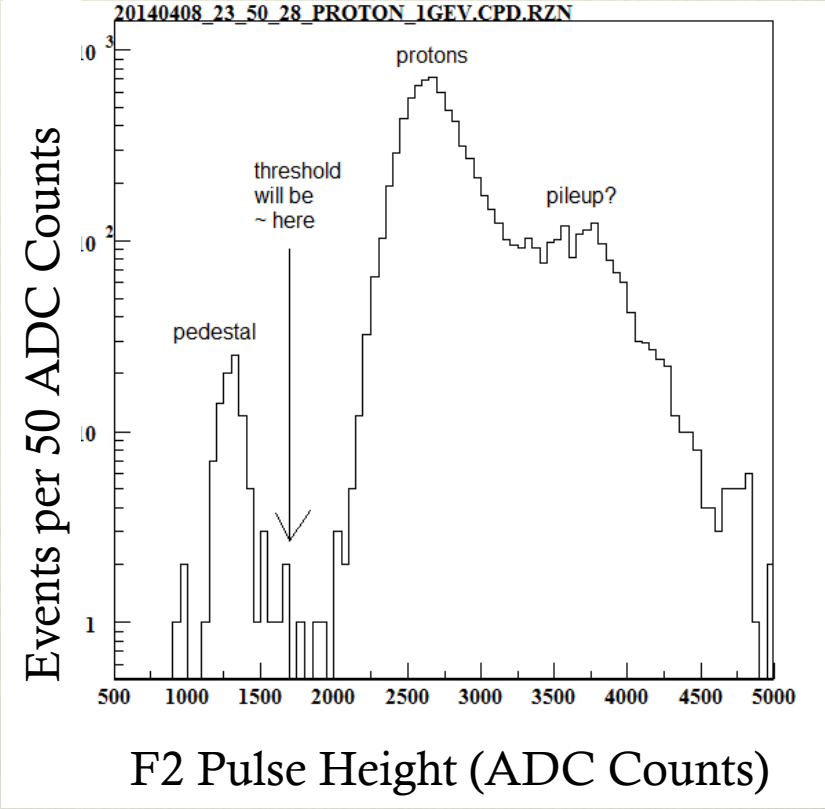
Operating Modes

- For EM calibration runs in 2013, only one subsystem was enabled at a time.
  - Avoided collisions of data packets in RIB.
  - Not flight-like.
- For FM, run as close to flight-like as possible.
  - Both enabled.
  - Some data corruption seen, resolved.

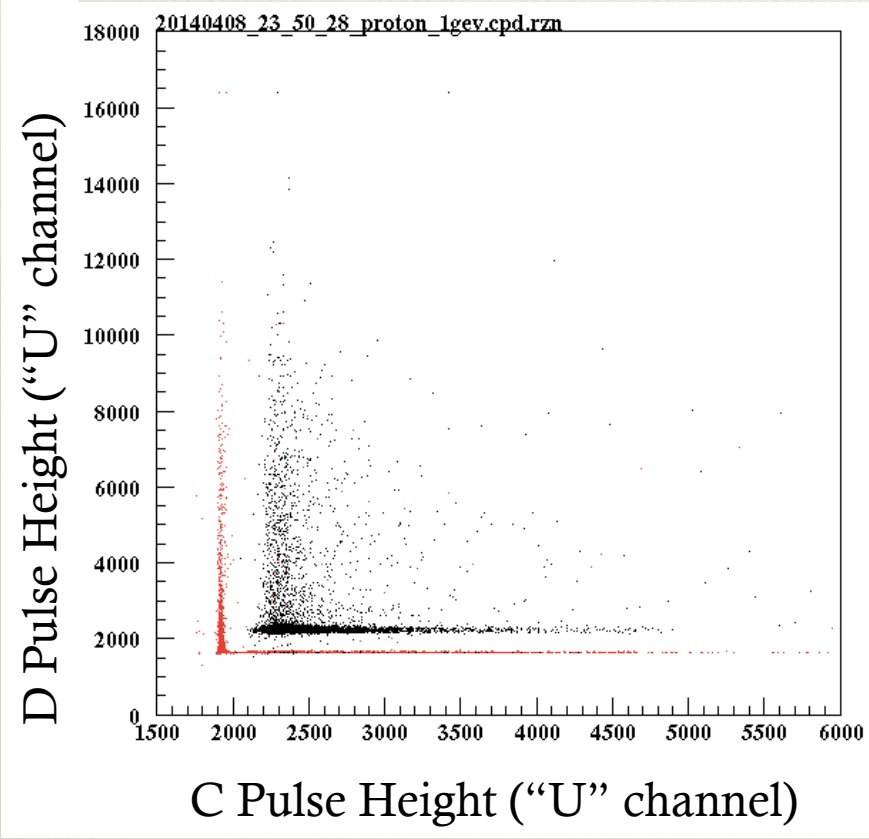
F2 with 1 GeV protons



- Proton peak (channel ~ 2600) well separated from pedestal (channel ~ 1300).
- Much cleaner than MSL-RAD → higher efficiency for neutral particle detection.

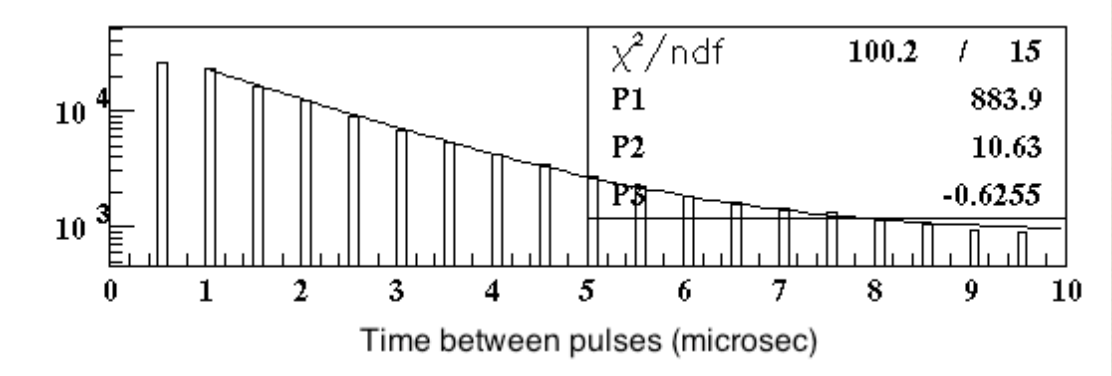


BGO vs. CsI



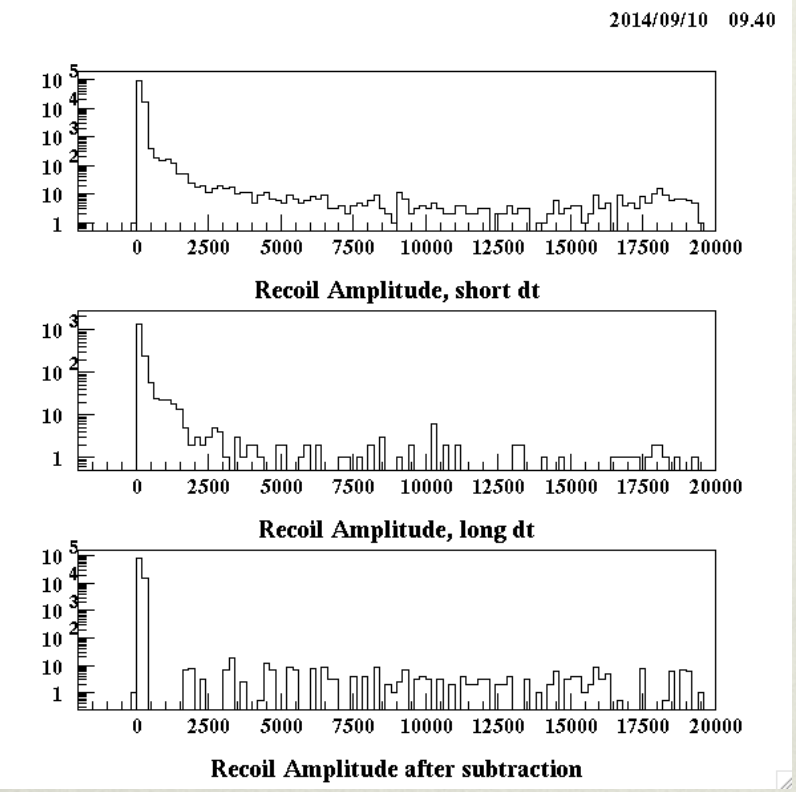
- 2.8 cm depth stops protons up to 120 MeV. (90 MeV in CsI.)
- Light yield reduced by ~ factor of 10 compared to CsI(Tl).
  - Still easily see min-I Z=1 ($\Delta E \sim 24$ MeV).
  - γ threshold ~ 10 MeV.
- Quenching study needed for stopping protons.

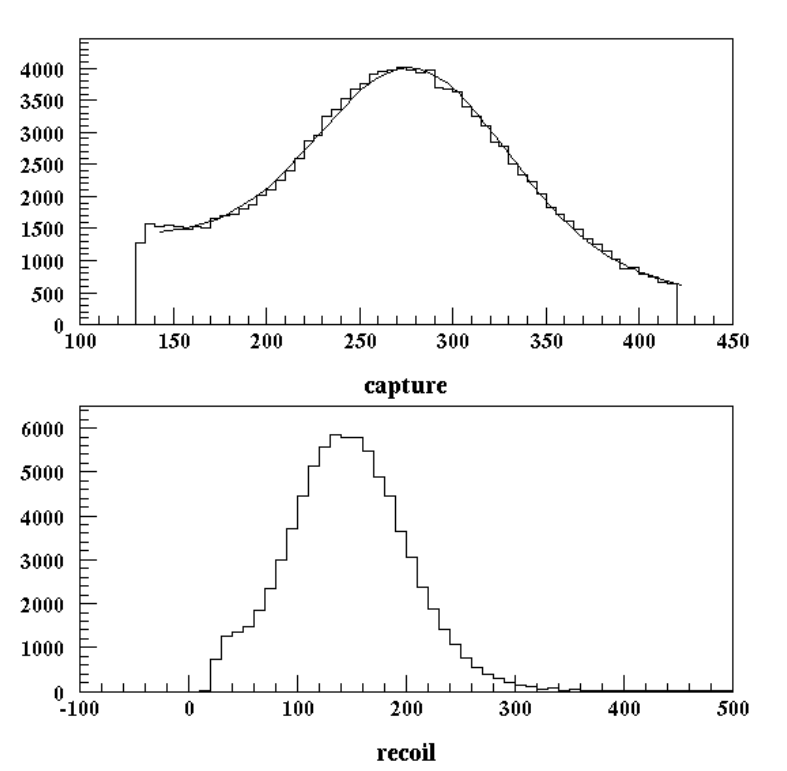
FND Sanity Check



- Random coincidences have flat distribution in Δt.
- Fit to constant (P1) + exponential (P2, P3).
- Mean of exponential = -1/P3 = 1.6 μs.
- Background events dominate at large values of Δt, neutrons dominate at small.

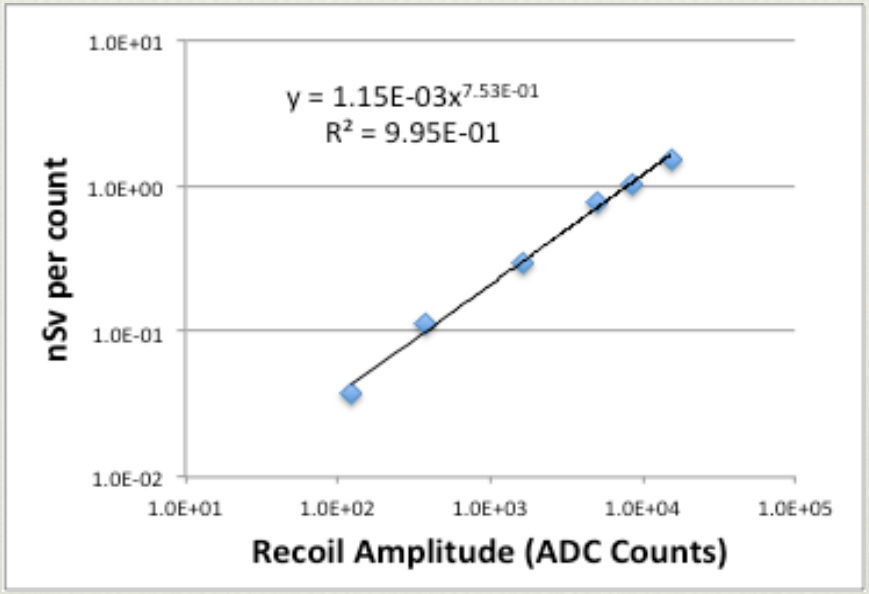
FND: 567 keV Neutrons





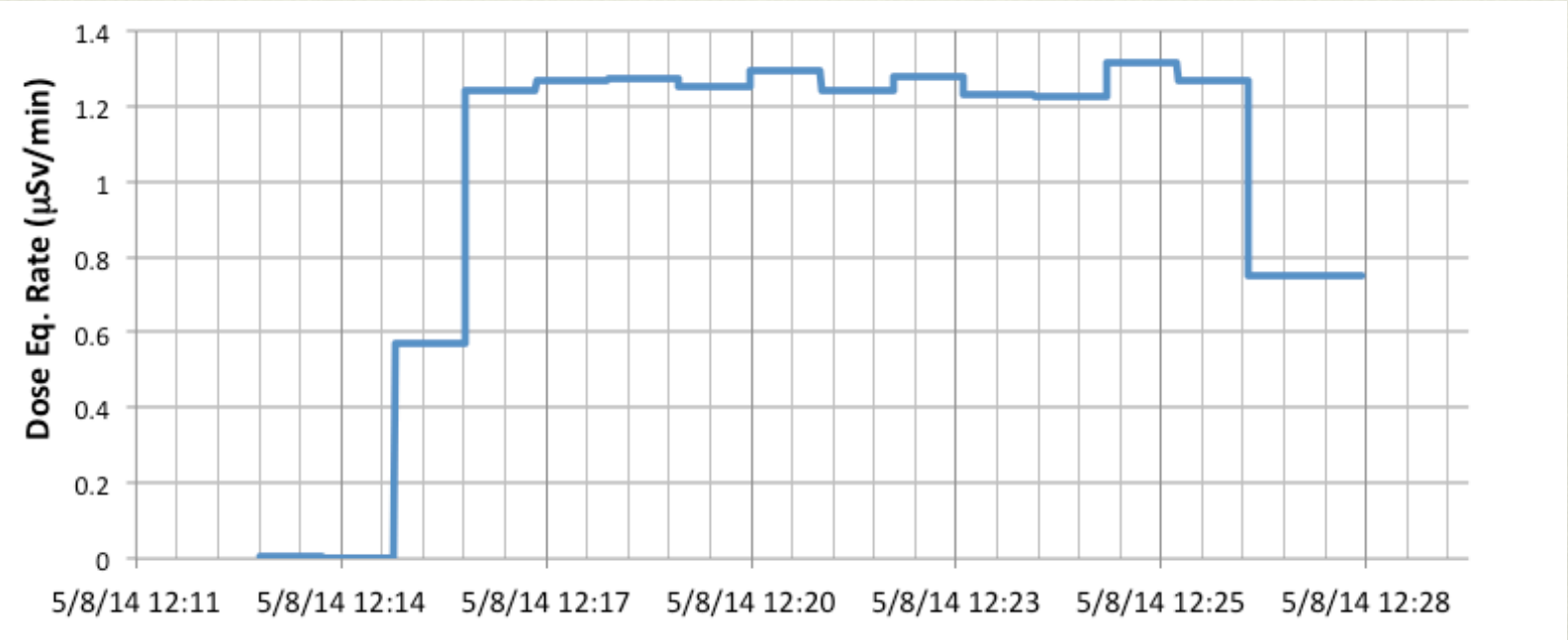
- Recoil spectrum at long Δt ~ background spectrum.
- Subtract → cleaned-up spectrum.
- Capture pulse spectrum fit suggests some background is present.
- Zoomed-in recoil spectrum ~ entirely above threshold.

Neutron Dose Equivalent vs. Recoil Amplitude



- Used PTB data to determine power law for EM.
- Folds in FND efficiency and dose equivalent vs. energy (ICRP74)
- Conversion factors (nSv/count) stored in look-up table (LUT), used in computation for cyclic data.
  - Will be updated when final FM calibration data obtained.
- Coarse algorithm used onboard (no background subtraction).

AmBe Test at PTB



- Expected dose equivalent rate = 0.93 µSv/minute.
- Conversion factors in LUT need refinement. (EM??)

Dose Equivalent Accuracy

- Improved accuracy in GAS compared to Cyclic.
  - More sophisticated algorithm.
  - Background subtraction (large Δt recoil spectrum).
- May need to include higher-energy neutrons measured in CPD.
  - CPD neutron spectrum unfolded with method used for MSL-RAD.

Charged Particle Calibration

- Gains & offsets used onboard.
- Calculated gains in silicon detector channels typically within ~ 5-10% of measured gains.
- Scintillator responses more complicated:
  - Calibrate to high-energy protons.
  - Within factors of 2 of estimates based on light yield from γ's.
  - Quenching, light yield, light collection efficiency all can vary from ideal, tend to give lower gain.

Conclusions

- ISS-RAD will be flown to ISS in first half of 2015.
- No chance to tweak settings for many months.
- CPD calibration & configuration close to final.
- FND calibration to be finalized after next PTB run.
- GAS to be delivered to JSC in next few weeks.