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Title: Introduction to neutron rem meters

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# Introduction to neutron rem meters

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CSU neutron class
Fort Collins, CO
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# Introduction: talk outline

- Discussion (brief) of neutron remmeters
  - Gas proportional counters
    - $^{3}$He(n,p)T and $^{10}$B(n,α)$^{7}$Li based instruments
    - Proton recoil counters
    - Activated foil-based instruments
  - Scintillator-based instruments

# $^{3}$He and $^{10}$B gas-based counters

- $^{10}$B
  - Uses $BF_3$ gas usually enriched to ~95% $^{10}$B
  - Limited to gas pressures of about 2atm maximum
  - Excellent gamma rejection properties
  - Boron-coated counters also used with a counting gas

- $^{3}$He
  - Often used with high Z gas to promote energy deposition
  - High pressure operation possible
  - Limited availability – DHD seeking alternatives
  - Very good gamma discrimination
  - Chemically inert (unlike $BF_3$)

# Gas proportional counters

- Secondary charged particles (p, α) ionize surround gas
- Electrons drift towards +ve charged central anode wire
- Electrons gain additional KE as electrical field increases
  - Generating additional electrons through collisions
- The overall gas multiplication effect gives rise to an enhanced anode current that is proportional to the initial energy deposited by the neutron interaction.

# Gas proportional counters

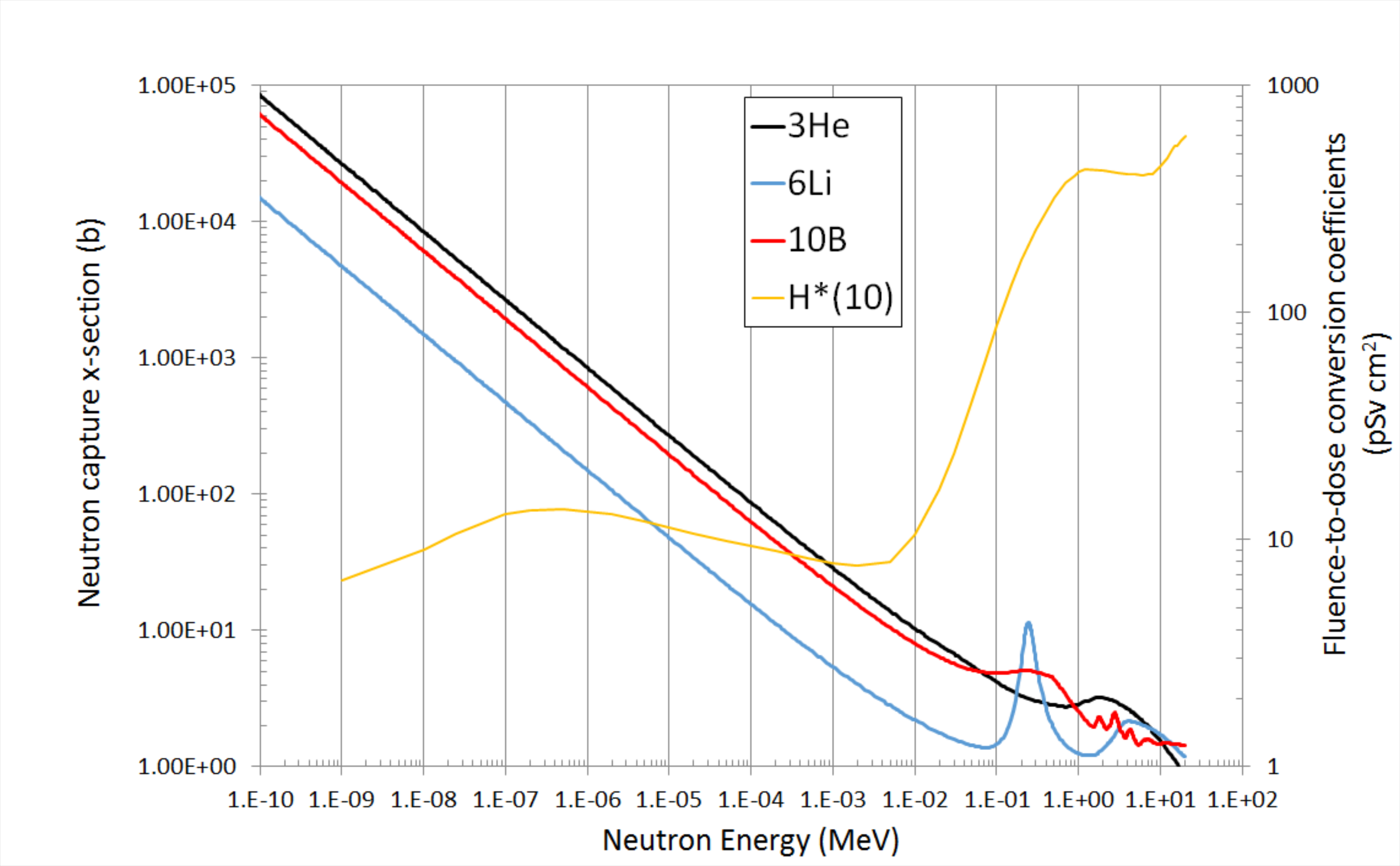
- An electronics assembly converts charge to a proportionally sized voltage pulse.
  - Electronic package also supplies the necessary bias voltage
- Electronics can be housed in an external rate meter or integrated into the detector housing.
- If voltage pulse exceeds a user-set discriminator level it is accepted as a neutron event.
- A calibration factor is then applied to convert counts to dose
- Typically two modes of operation: scalar and rate mode

# Instruments based on thermal neutron capture

- Energy response of bare counter is unacceptable.
- Response is highest in region where dose per neutron is lowest and *vice versa* .
- Solution is to modify the incident spectrum to improve the instrument response

- Adding a shell of PE gives a more tissue-like response
  - 9” diameter sphere is typically used
  - Cd or B-loaded PE internal shell often used as well
    - Perforating this shell further improves energy response
  - But there is a weight penalty

# Comparison of neutron capture x-sections with H*(10) curve



# Instruments based on thermal neutron capture

Hankin’s design

Anderson Braun design

Typical sensitivity: 40cpm per mrem/h per atm.

Energy response: no better than ±30%

Weight: no less than 20lbs

Resolving time ~ 5-10 μs

Canberra DiNeutron : Uses two PE-moderated detectors

# Instruments based on thermal neutron capture: high-energy neutron response

Thermo's SWENDI II

High energy response boosted by adding high Z shell (e.g. Bi or W) to generate additional neutrons via (n, xn) reactions.

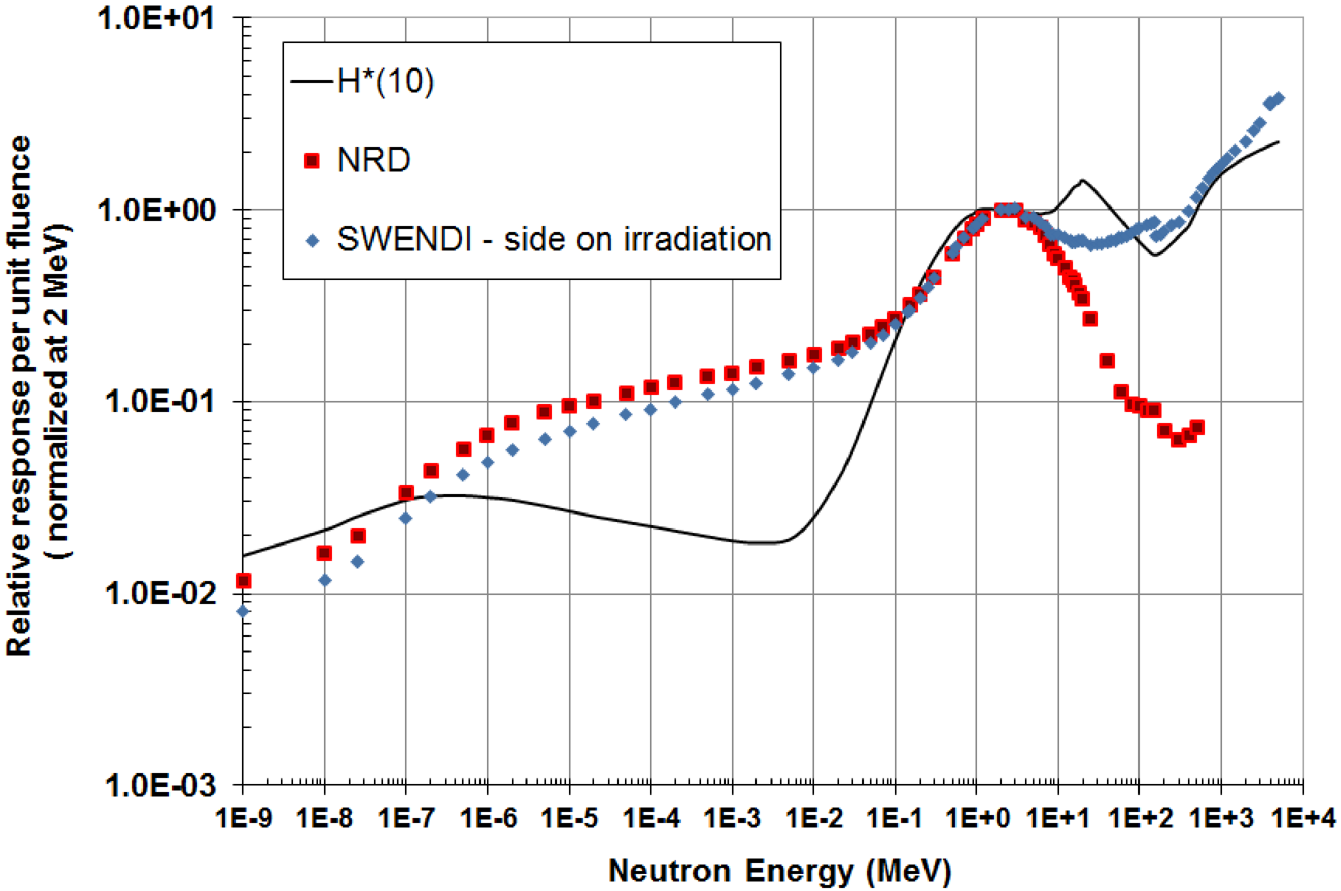
Typical sensitivity: 300cpm per mrem/h per atm.

Energy range: extended from 20MeV to 5 GeV

Weight: no less than 30lbs

HPI 6060

# Instruments based on thermal neutron capture: energy response



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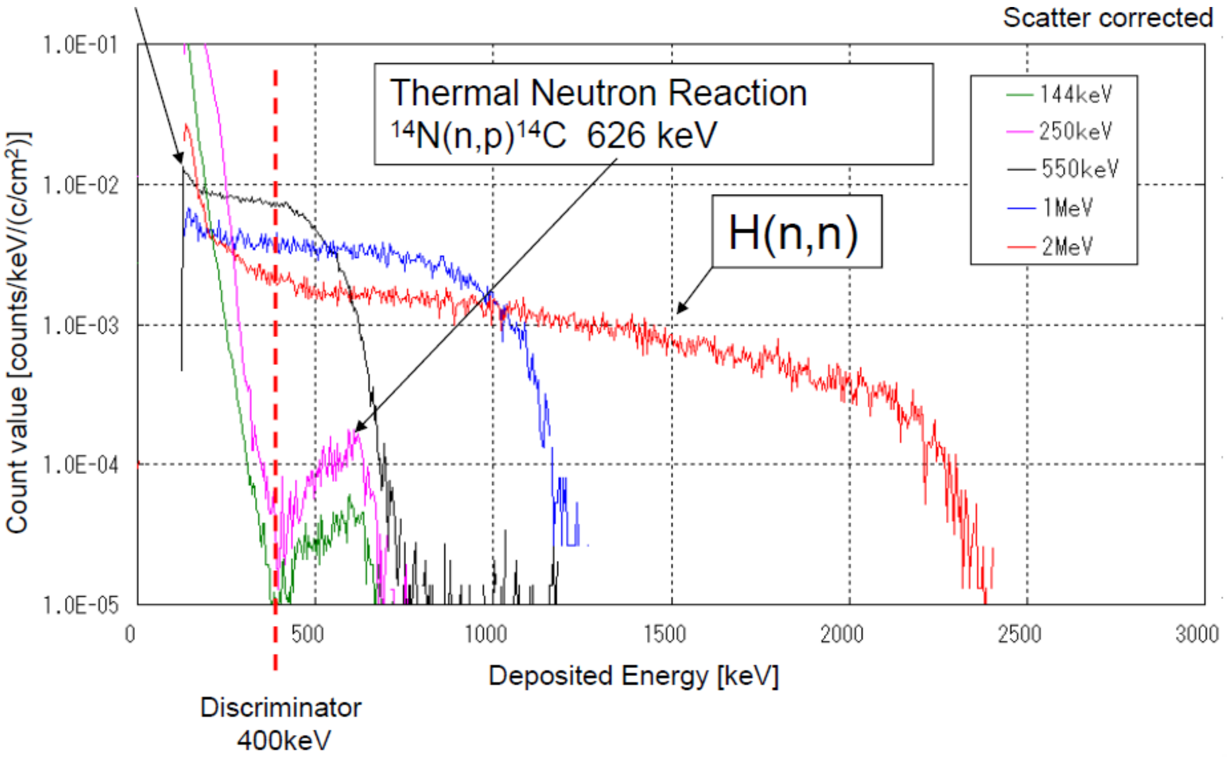
# Fuji NSN3 remmeter

- Two gas-based detectors in single sealed gas proportional counter.
  - Thermal detector based on $^{14}N(n,p)^{14}C$ rxn Ep=0.626 MeV
    - 0.98 atm of $N_2$
  - Fast neutron detector based on proton recoil
    - 3.98 atm of $CH_4$
  - Total volume = 1.5 l
  - Total weight = 5.1 lbs

# Fuji NSN3 remmeter

- Uses a minimal amount of PE moderation
- Incorporates an MCA to obtain pulse height spectrum.



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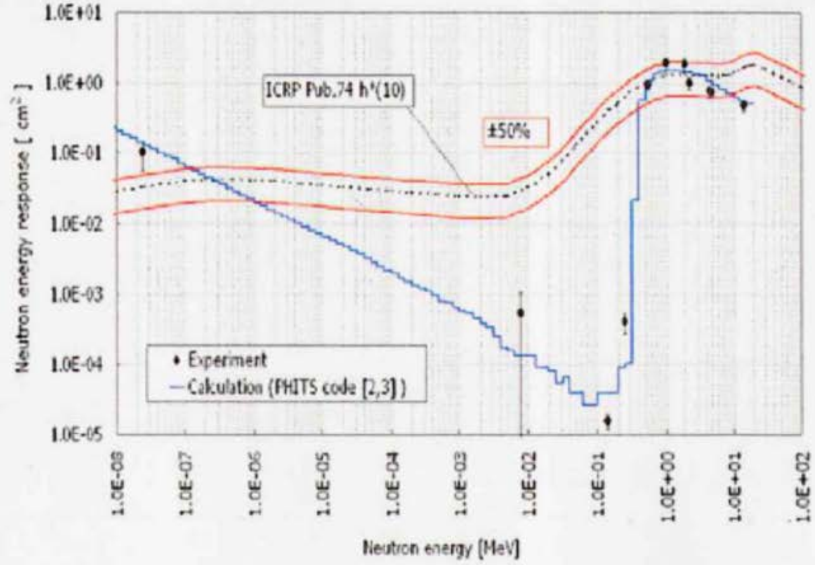
# Fuji NSN3 remmeter

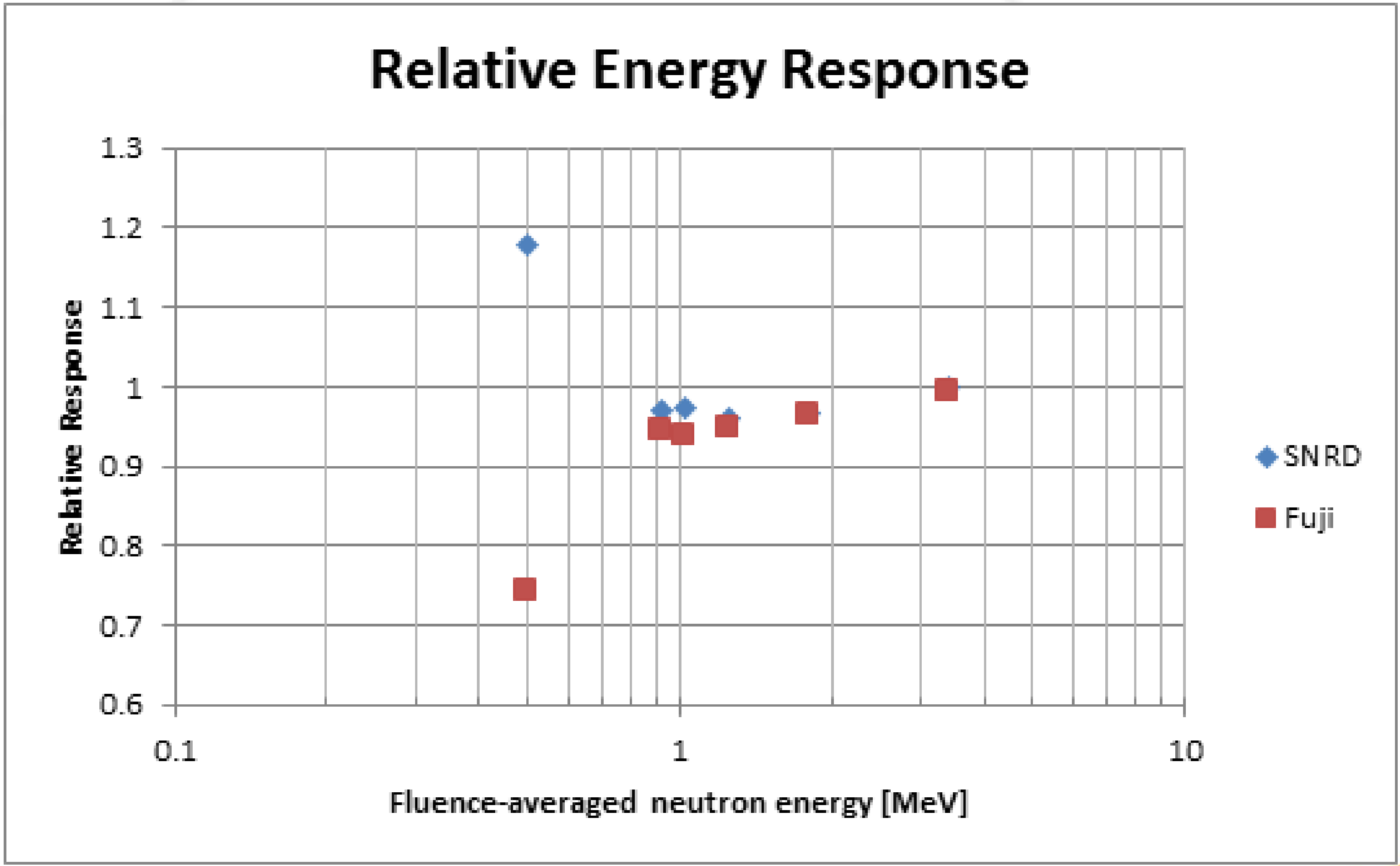
- Pulse height spectrum is analyzed to yield neutron dose using a single optimized calibration constant.
- Energy response data:

·Neutron energy response



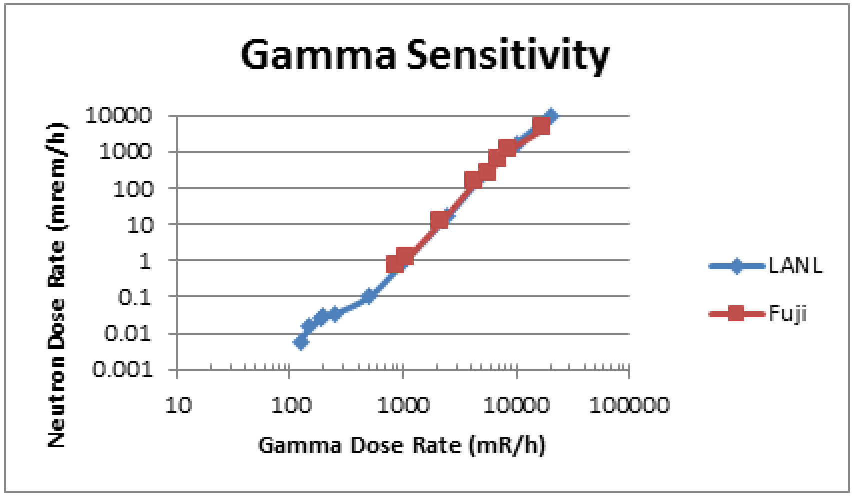
| Monoenergetic neutron energy | Response [ $cm^2$ ] |
|---|---|
| 8 keV | 5.0E-4 |
| 144 keV | 1.6E-5 |
| 250 keV | 4.1E-4 |
| 550 keV | 1.01 |
| 1 MeV | 1.94 |
| 2 MeV | 1.84 |
| 5 MeV | 0.76 |
| 14.8 MeV | 0.50 |

# Fuji NSN3 remmeter: LANL data



# Fuji NSN3 remmeter

- Energy response of ±20% claimed
- Sensitivity about same as NRD
- Gamma rejection is not as good as $BF_3$ or $^3$He-based instruments



- Problem with transporting due to high-pressure flammable gas

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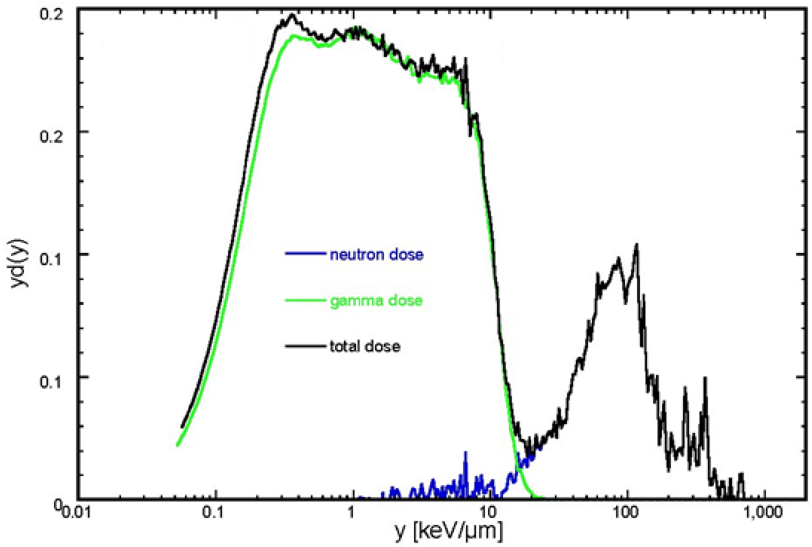
# Tissue equivalent counter

HPI REM500

- Based on lineal energy transfer in tissue equivalent gas surrounded by TE plastic.
- Lineal energy = deposited energy/ Avr. chord length of spherical gas cell.
- MCA used to obtain lineal energy spectrum.
- Quality factor based on lineal energy corresponding to each channel is applied to the counts in that channel to calculate dose equivalent

# Tissue equivalent counter



- Low energy events overlap gamma spectrum
- Sensitivity is relatively low at 8 cpm per mrem/h
- But, in principle, gives best possible estimate of dose equivalent
- Weight is only 5lbs

# Instrument performance comparison

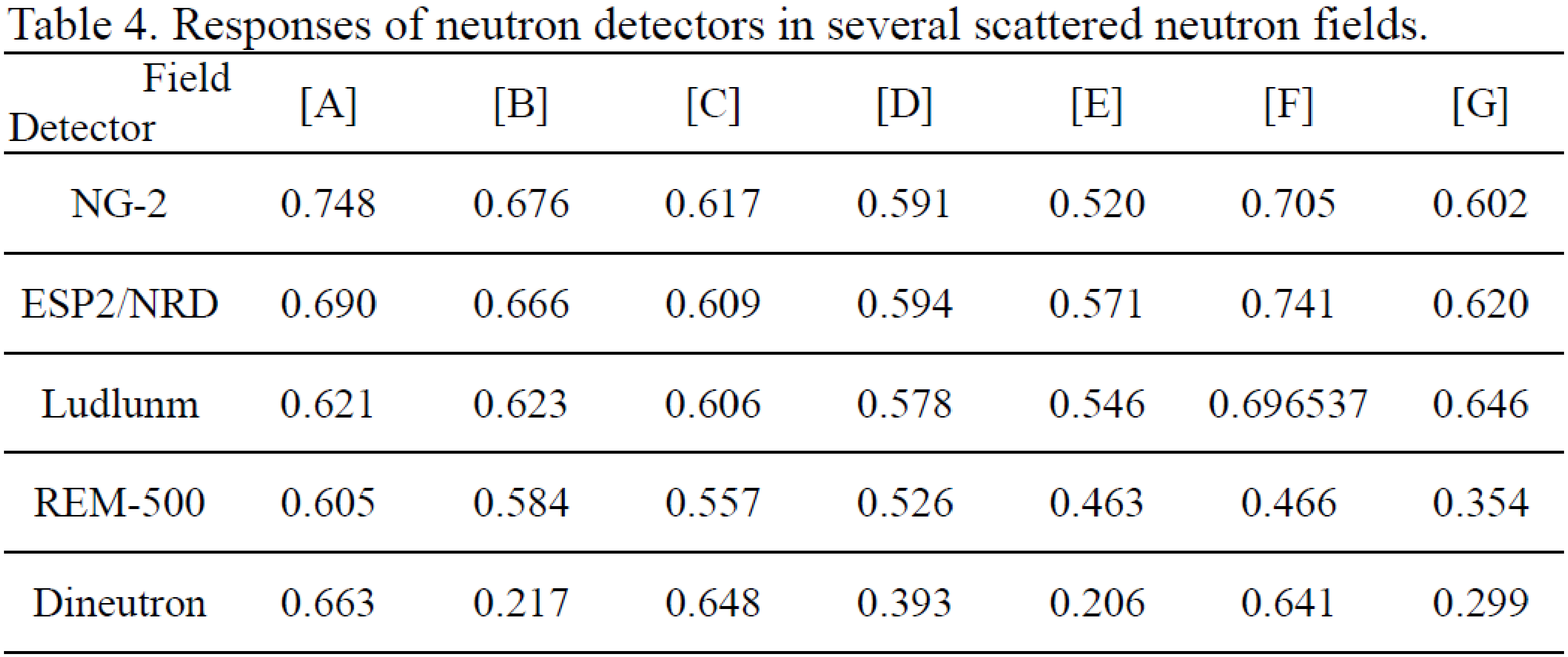


Table 4. Responses of neutron detectors in several scattered neutron fields.

| Field<br>Detector | [A] | [B] | [C] | [D] | [E] | [F] | [G] |
|---|---|---|---|---|---|---|---|
| NG-2 | 0.748 | 0.676 | 0.617 | 0.591 | 0.520 | 0.705 | 0.602 |
| ESP2/NRD | 0.690 | 0.666 | 0.609 | 0.594 | 0.571 | 0.741 | 0.620 |
| Ludlunm | 0.621 | 0.623 | 0.606 | 0.578 | 0.546 | 0.696537 | 0.646 |
| REM-500 | 0.605 | 0.584 | 0.557 | 0.526 | 0.463 | 0.466 | 0.354 |
| Dineutron | 0.663 | 0.217 | 0.648 | 0.393 | 0.206 | 0.641 | 0.299 |

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# Pulsed field performance

- Accelerator fields are frequently pulsed resulting in high instantaneous neutron fluence and dose rates.
- Neutron rem meters using PE-moderators are somewhat immune due to the time required to thermalize fast neutrons (typically 50-100 µs) – effectively lengthening the pulse.
- But there are limitations on the effectiveness of the PE moderator and other means of neutron dose measurements are required
- E.g. ion chambers in current mode
  - Boron-lined chambers or chambers with TE walls and gas

# Pulsed field performance

- The HPI 2080 ("Albatross") is designed to operate in pulsed (and static) fields.
- Standard PE-moderator approach
- But uses two GM tubes
  - One surrounded by Ag foil the other with an equivalent mass thickness of tin.
  - The Ag foil is activated through TNA
    - Its GM tube counts subsequent beta decay
  - The second GM compensates for the gamma background

$^{108}$Ag ($t_{1/2}$ = 145 s)

$^{110}$Ag ($t_{1/2}$ = 25 s)

# Pulsed field performance

- Sensitivity is relatively low at 30 cpm per mrem/h
- Energy response similar to PE-moderated instruments
- Weight is 25lbs
- A high-energy enhanced response instrument version (“Eagle”) is also available

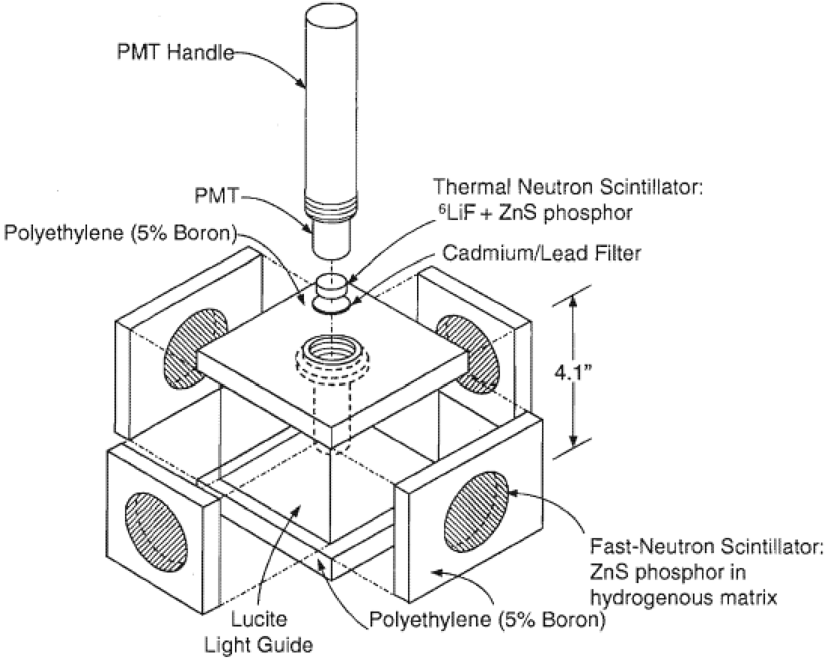
# Scintillator-based instruments

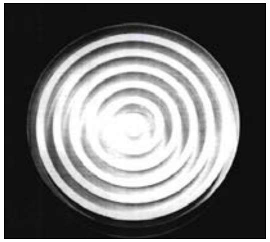
- Not in wide spread use due gamma discrimination not being nearly as good as $^{10}BF_3$ and $^{3}He$ gas counters.
- Gas-based instruments also more rugged due to PE shell
- But scintillation-based instruments don’t necessarily require use of a heavy PE moderator.
  - A definite ergonomic advantage

# Scintillator-based instruments: PRESCILA

- **P**roton **Re**coil **Sc**intillator **L**os **A**lamos
- Developed at LANL and commercialized by Ludlum Inc.
- Utilizes a dual detector approach (like the Fuji NSN3) for fast and thermal neutron detection.
- Weight = 6lbs
- Benefited from extensive Monte Carlo modelling to optimize design

# Scintillator-based instruments: PRESCILA

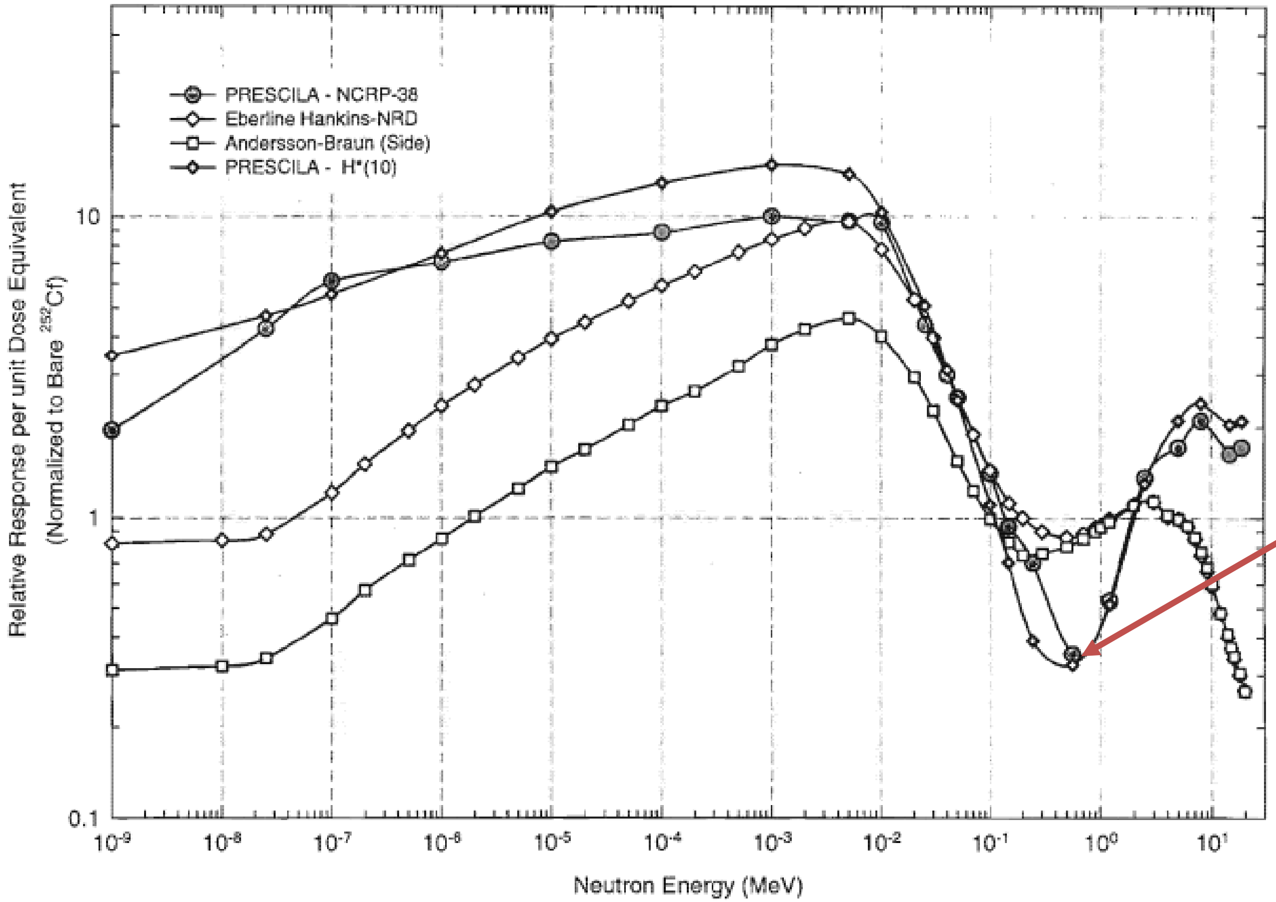




Eljen EJ-410P ZnS(Ag)-filled rings surrounded by lucite

- Fast detector comprised of 5 EJ-410P scintillators
  - Recoil protons generated in lucite excite ZnS(Ag)
  - Light emission collected by lucite light guide and detected by central PMT
- Thermal channel is comprised of a $^{6}$LiF+ZnS(Ag) scintillator
  - $^{6}$Li content commensurate if fast detector response

# PRESCILA: Dose response and comparison



PRESCILA under response where fast and thermal detectors overlap

# PRESCILA

- Limitation of using a single PMT creates a minimum dose response where the fast and thermal energy ranges overlap (same effect seen in the Fuji probe)
- Sensitivity ~ 100 cpm per mrem/h
- Gamma breakthrough observed above 50 mR/h
  - Pb lining later added to reduce gamma response
- Not currently in use at LANL

# Other scintillators

- Liquefied rare gases
- $^6$Li-based glasses
- $Cs_2LiYCl_6$:Ce  (CLYC)

# Calibration of neutron rem meters

- Require NIST-traceable source or instrument cal.
  - $^{252}$Cf or $^{241}$AmBe most often used

- Need to characterize neutron field (dose rate vs distance from source)
  - Measurements and/or Monte Carlo calculations

- Instruments should be calibrated in a field which gives the most conservative calibration factor
  - Function of instrument energy response and the workplace field

# Some points to consider in selecting a neutron rem meter

- Energy response
- Angular response
- Neutron sensitivity
- Gamma rejection
- Ergonomics
- Calibration source
- Reliability
- Pulsed field performance
- Ease of:
  - use, maintenance/repair and calibration
- Transportation issues
  - hazardous gases and/or high pressures