



Introduction to neutron rem meters

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Introduction: talk outline

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

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^3He 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

■ ^3He

- Often used with high Z gas to promote energy deposition
- High pressure operation possible
- Limited availability – DHS seeking alternatives
- Very good gamma discrimination
- Chemically inert (unlike BF_3)

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Gas proportional counters

- Secondary charged particles ionize surrounding 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.

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Gas proportional counters

- An electronics assembly converts charge to a proportionally sized voltage pulse.
 - Electronics 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

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Instruments based on thermal neutron capture

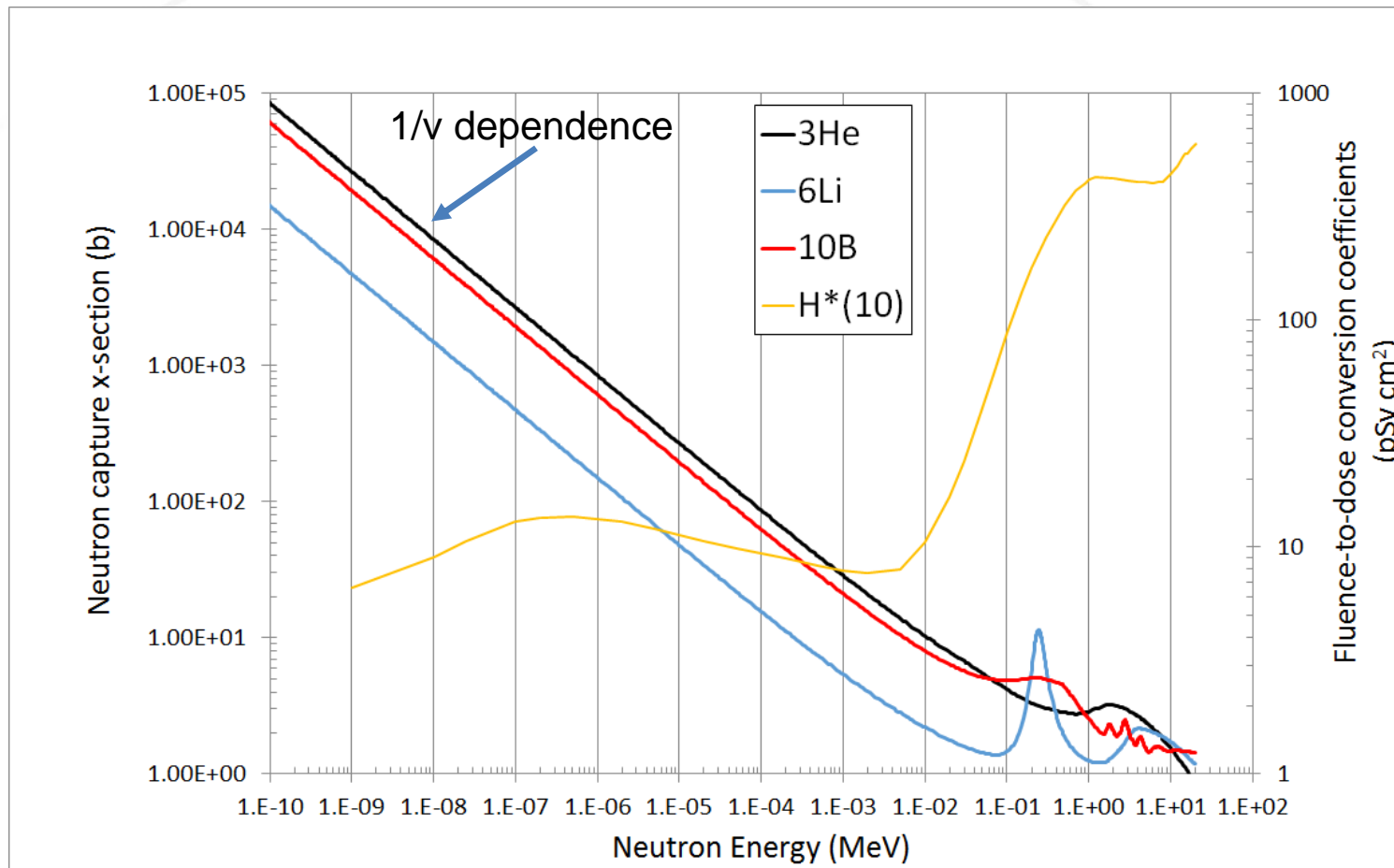


- Energy response of bare counter is unacceptable.
 - Response is highest in region where dose per neutron is lowest and *vice versa* .
 - Solution is to modify the incident spectrum to improve the instrument response
-
- Adding a shell of PE gives a more tissue-like response
 - 9" diameter sphere is typically used
 - Cd metal or a B-loaded PE internal shell often used as well
 - Perforating this shell further improves energy response
 - But there is a weight penalty

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



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Instruments based on thermal neutron capture



Hankin's design



Andersson Braun design

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

Energy response: typically no better than $\pm 30\%$

Weight: no less than 20lbs

Resolving time $\sim 5-10 \mu\text{s}$

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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

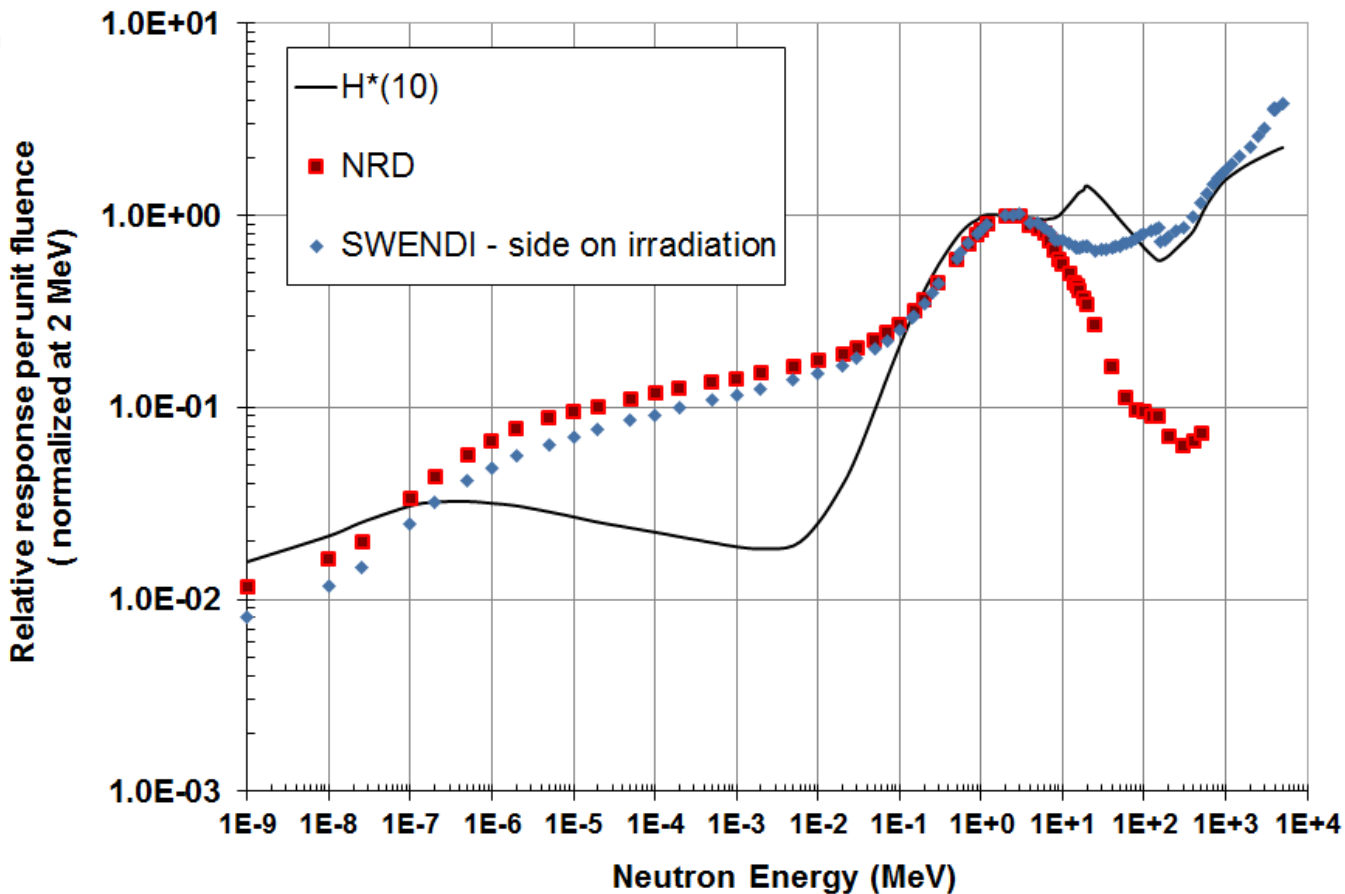


HPI 6060

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Instruments based on thermal neutron capture: energy response



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Fuji NSN3 rem meter

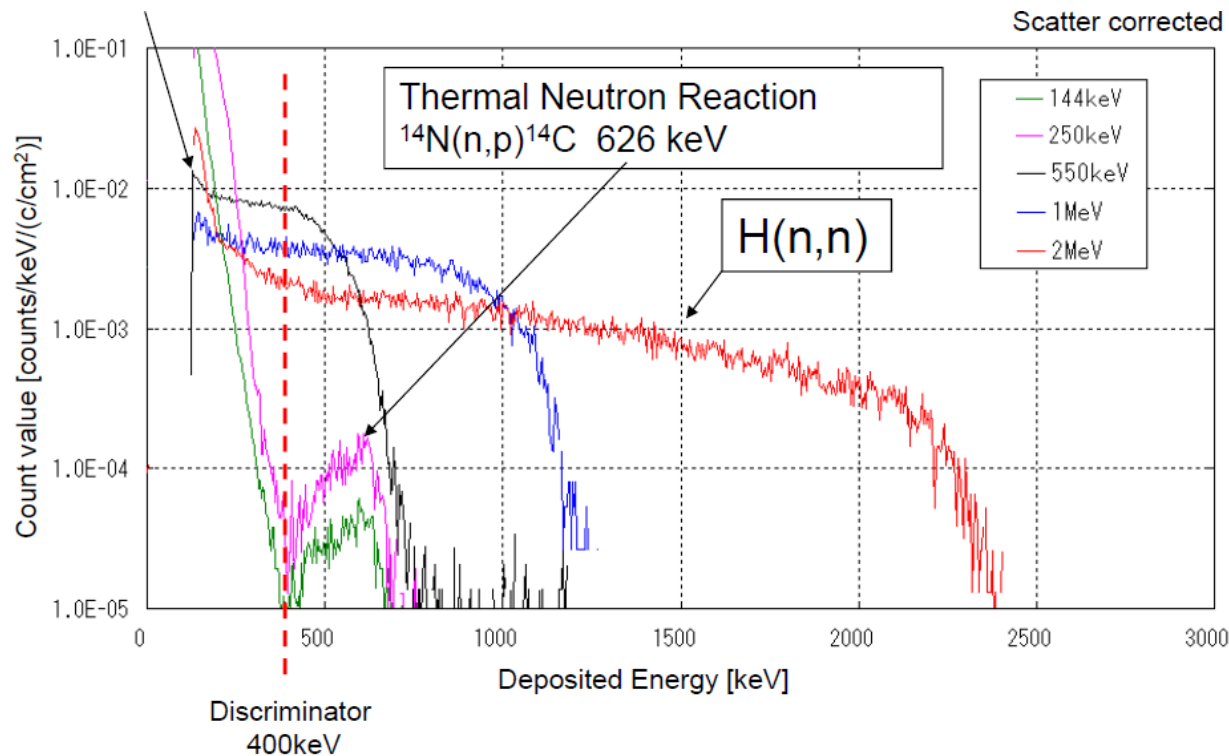


- Two gas-based detectors in a single sealed gas proportional counter.
 - Thermal detector based on $^{14}\text{N}(n,p)^{14}\text{C}$ rxn $E_p=0.626$ MeV
 - 0.98 atm of N_2
 - Fast neutron detector based on proton recoil
 - 3.98 atm of CH_4
 - Total volume = 1.5 l
 - Total weight = 5.1 lbs

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Fuji NSN3 rem meter

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



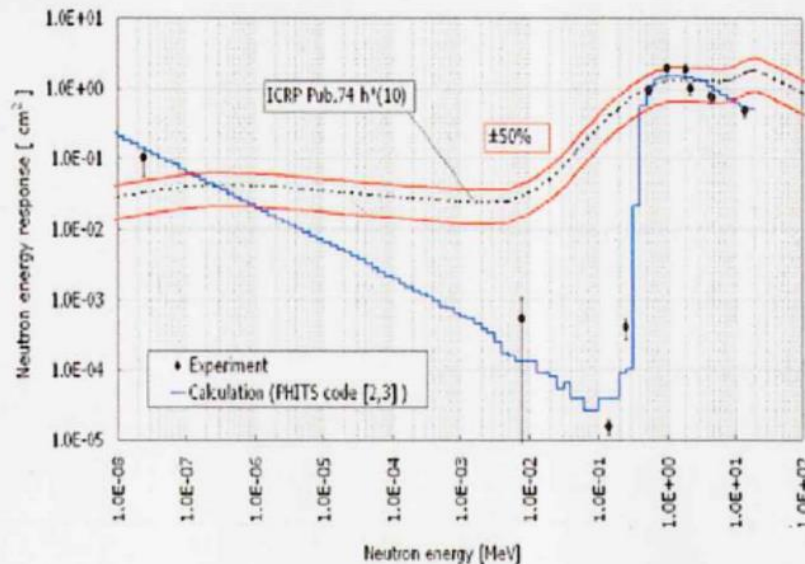
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Fuji NSN3 rem meter

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

• Neutron energy response

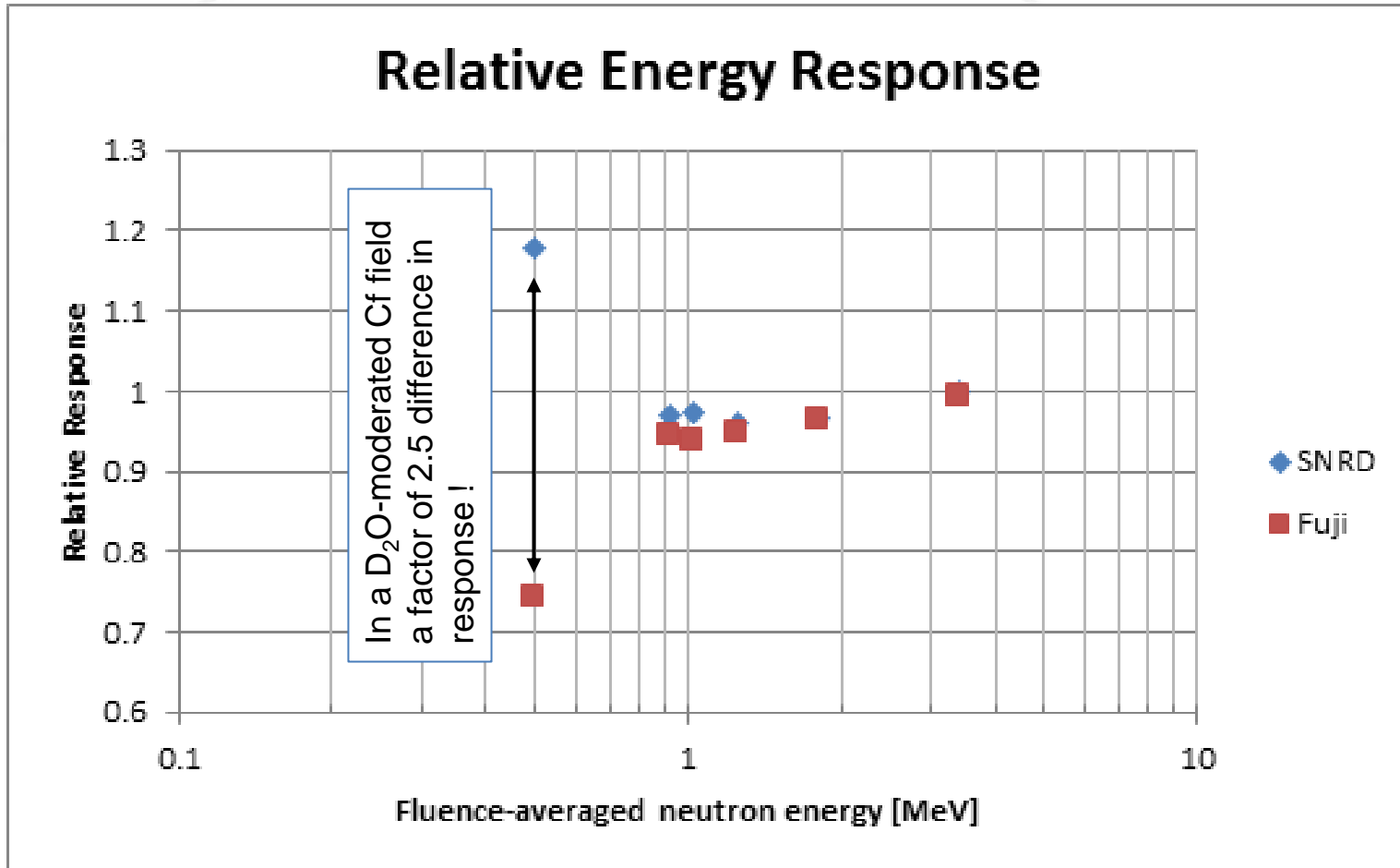


Monoenergetic neutron energy	Response [cm ²]
8 keV	5.0E-4
144 keV	1.6E-5
250 keV	4.1E-4
550 keV	1.01
1 MeV	1.94
2 MeV	1.84
5 MeV	0.76
14.8 MeV	0.50

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Fuji NSN3 rem meter: LANL data

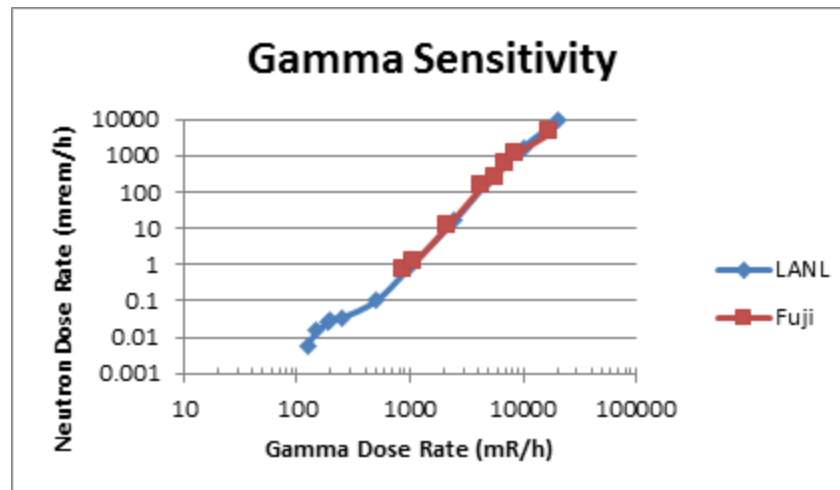


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Fuji NSN3 rem meter

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



- Problem with transporting due to high-pressure flammable gas

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Tissue equivalent counter



HPI REM500

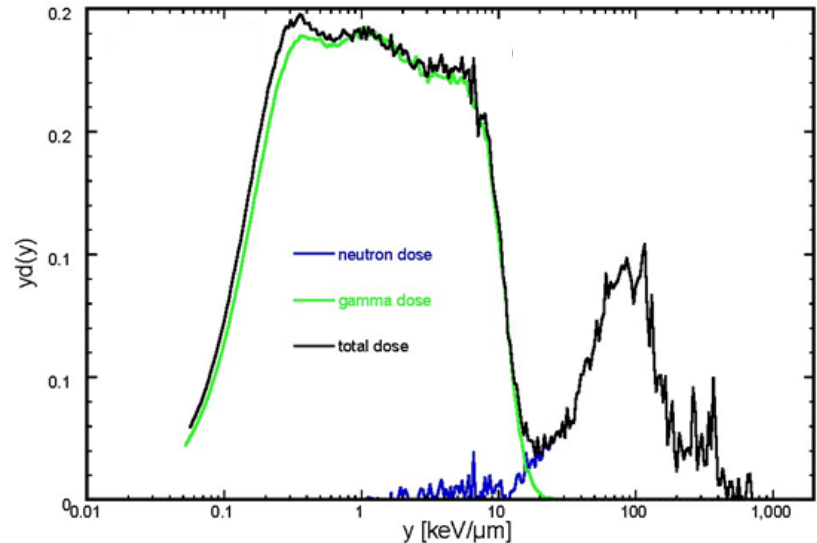
- Based on lineal energy transfer in tissue equivalent gas surrounded by TE plastic.
- Lineal energy = deposited energy/ average chord length ($4r/3$) of spherical gas cell .
- MCA used to obtain lineal energy spectrum.
- A Quality factor - based on lineal energy corresponding to each channel - is applied to the counts in that channel to calculate its dose equivalent contribution. Summation over all channels gives total dose equivalent.

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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



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Instrument performance comparison

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

Field 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
Ludlum	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

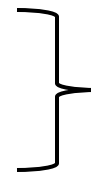
- Accelerator fields are frequently pulsed resulting in high instantaneous neutron fluence and dose rates.
- Neutron rem meters using PE-moderators are somewhat immune due to the time required to thermalize fast neutrons (typically 50-100 μ s) – effectively lengthening the pulse.
- But there are limitations 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

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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 decays
 - The second GM compensates for the gamma background



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

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

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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



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Scintillator-based instruments

- Not in wide spread use due to gamma discrimination not being nearly as good as $^{10}\text{BF}_3$ and ^3He 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

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Scintillator-based instruments: PRESCILA

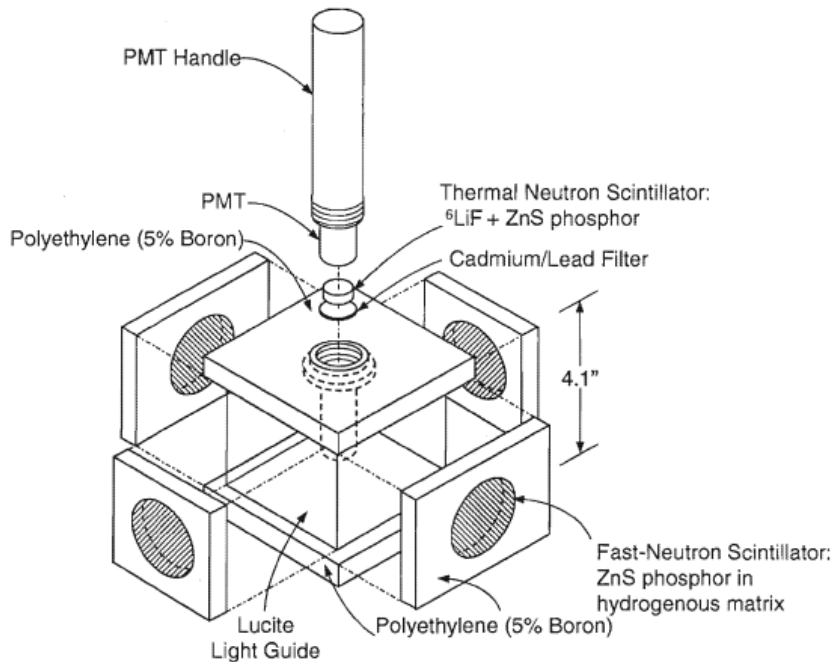
- **Proton Recoil Scintillator Los Alamos**
- Developed at LANL and commercialized by Ludlum Inc.
- Utilizes a dual detector approach (like the Fuji NSN3) for fast and thermal neutron detection.
- Weight = 6lbs
- Benefited from extensive Monte Carlo modelling to optimize design



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Scintillator-based instruments: PRESCILA



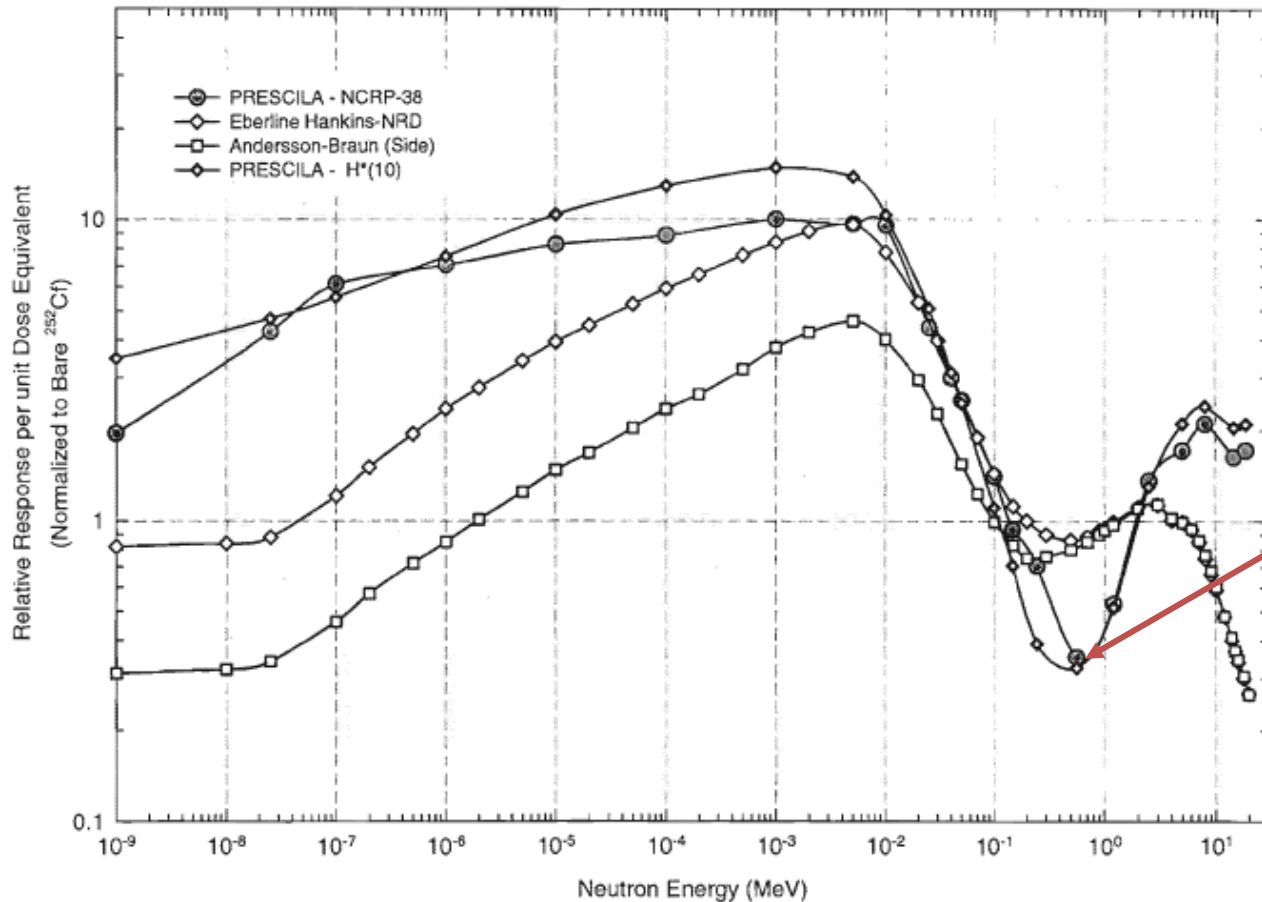
Eljen EJ-410P
ZnS(Ag)-filled
rings
surrounded by
lucite

- 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 ${}^6\text{LiF} + \text{ZnS(Ag)}$ scintillator
 - ${}^6\text{Li}$ content commensurate with fast detector response

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PRESCILA: Dose response and comparison



PRESCILA under response where fast and thermal detectors overlap

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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



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Other scintillators

- Liquefied rare gases
- ^6Li -based glasses
- $\text{Cs}_2\text{LiYCl}_6:\text{Ce}$ (CLYC)

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Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

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Calibration of neutron rem meters

- Require NIST-traceable source or instrument cal.
 - ^{252}Cf or $^{241}\text{AmBe}$ 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

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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

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