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Am-Be Versus Neutron Generator-based Alternatives for Well Logging Measurements

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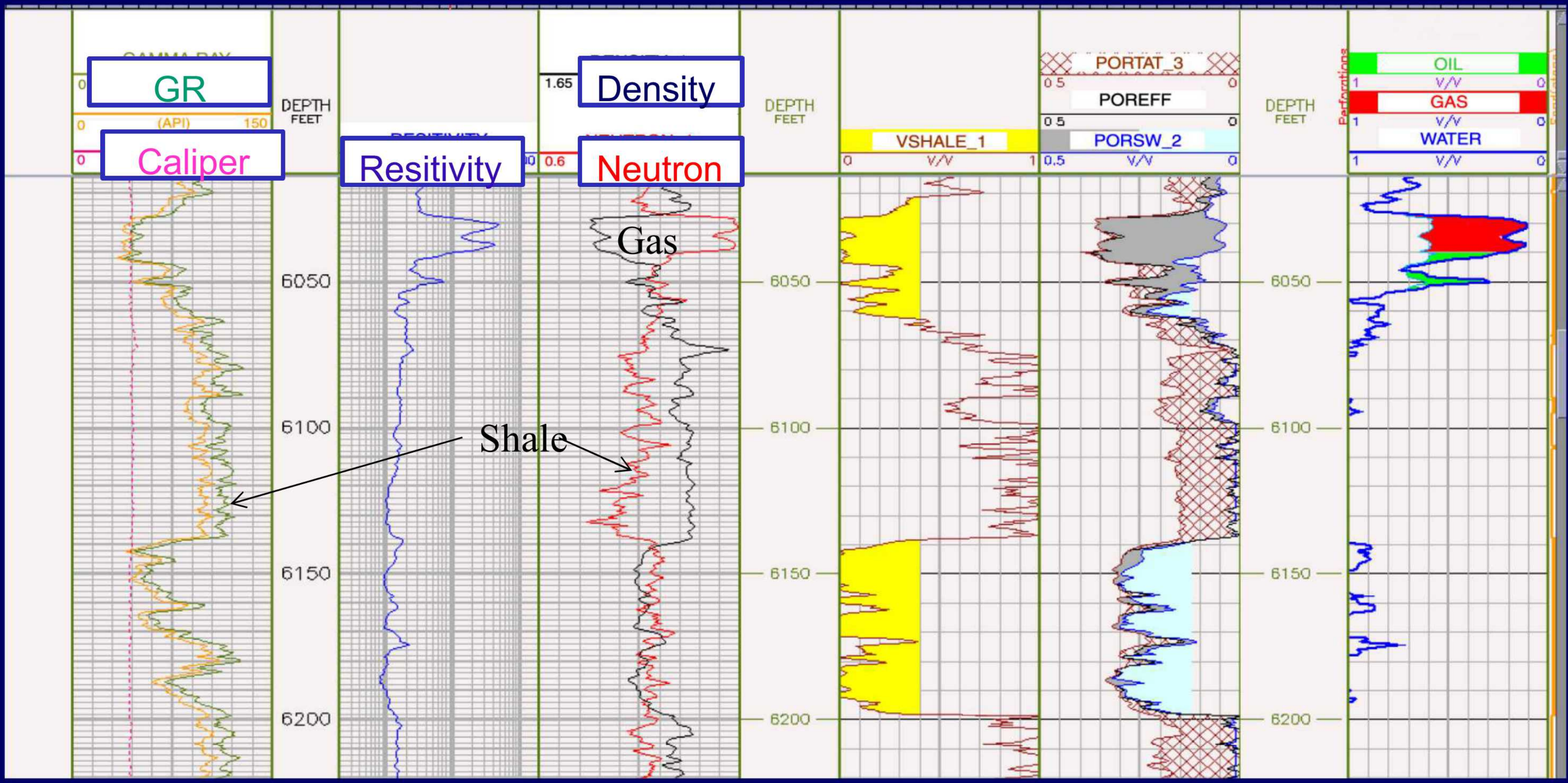
Presentation

- Premise of the talk- Replace Am-Be Sources used in well logging- Why?
- State of *Tested* Alternatives
- Requirements to be a replacement
- Present Study: Various neutron generators vs. Am-Be, from a user perspective
- Response Characteristics Considered: Mainly porosity, w/ comments on (n-ɣ) spectroscopy
- Summary

A simple wireline open-hole reservoir characterization

(Badruzzaman, Proc. Am. Nucl. Soc. Topical Conf. Santa Fe, NM, 2002)



- Density: Porosity; GR and Neutron: Shale/Lithology; Neutron-Density: Gas
- Electrical resistivity: Hydrocarbon
- Neutron only choice, if GR unusable

Wells can be costly $\Rightarrow$ Good data must $\Rightarrow$ Reserves & place wells?

Porosity Accuracy: Reserves Uncertainty with 1 Porosity Unit (pu) Error

(Fig: Badruzzaman et al., SPE 123593, 2009)

Porosity (pu)	Reserve = 100 million barrels	Reserve = 1 billion barrels	Reserve = 10 Billion barrels	Reserve = 50 billion barrels
5	20 million	200 million	2 billion	10 billion
15	6.7 million	67 million	670 million	3.33 billion
30	3.33 million	33 million	333 million	1.67 billion

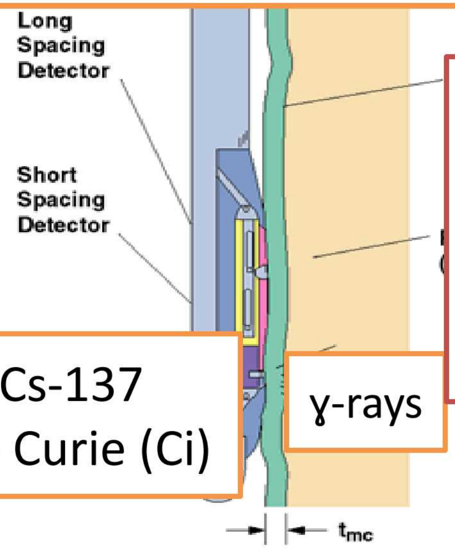
- Some major reservoirs: 5-10 pu; nominal reserve: 50+ billion bbl
- Cs-137 source density: 1-pu or better in porosity
- Marketed alternatives- level of accuracy?

Erroneous well placement:: $$$$$; risky

Well Logging Sources & their Risk Profile

Radionuclide-based Tools & Risk Category

Wireline Density/PE



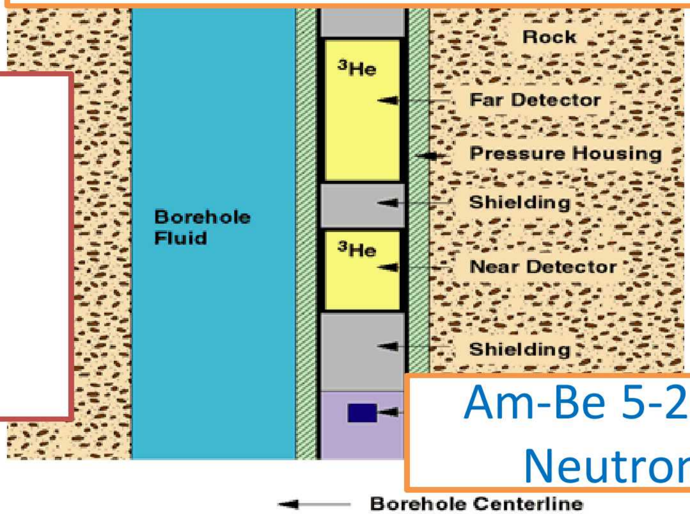
Cs 137: Cat 3
Am-Be: Cat 3- Cat 2

Cat 2: Death
Cat 3: Permanent Injury

Cs-137
2-3 Curie (Ci)

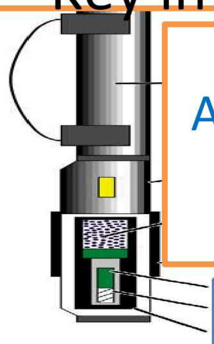
ɣ-rays

Wireline Neutron Tool



Am-Be 5-20 Ci
Neutrons

Mineralogy
Key in unconventionals



Am-Be 16 Ci neutron Src- being replaced by generators ⇒better mineralogy

Detect produced ɣ- rays.

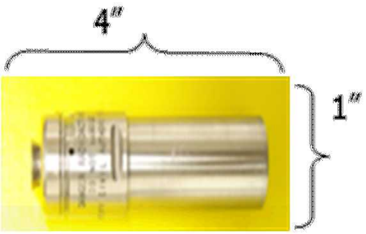
LWD tools look different; use same sources

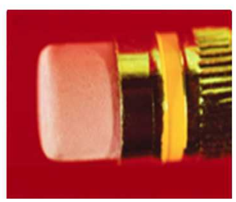
Conglomerate of sources can bump-up risk

Logging Source Protections

Source material: *Doubly-encapsulated in steel @ 25+ Kpsi. Cs-137 src material in glass matrix.*

A Cs-137 Source: Capsule (left); actual source (right) (Ref: Badruzzaman et al, SPE 123593, 2009)





An Am-Be Source Capsule (Ref: Hearn, WINS Workshop, Paris, 2014)

A Neutron Source Container | A Density Source Container

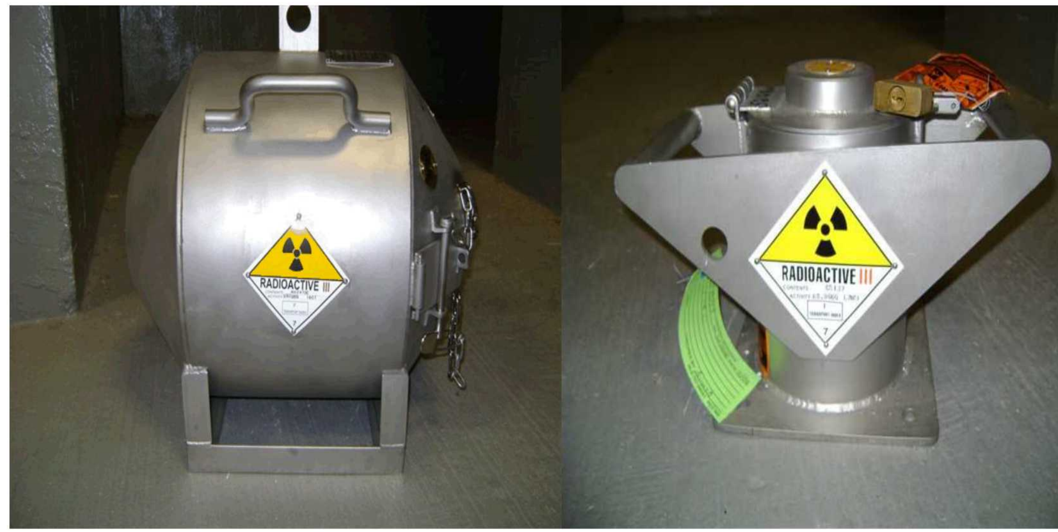


Figure: Courtesy of Halliburton (Ref: SPE 123593, 2009)

Storage: Secure vaults (company or government)

Transport: Shielded containers compliant with government or International Atomic Energy Agency (IAEA) protocols

***Why the concern?* Loss of Control ⇒ Diversion ⇒ Radiological dispersal device**

Recent Logging Source Incidents: *Examples*

- Theft: Argentina (2009); India (1993)
- Lost/missing: Kazakhstan(2014);TX (2012); Nigeria (2003)
- Conflict zones: Libya (2013); Syria (2012/2013); Colombia (1998)
- Breached: California (2006)
- Multi-faceted impact

Alternative Tech: Ultimate Mitigation- A Perspective

- Industry: 37+ yr. R& D - Nonnuclear and Nuclear Alt-tech

- Post-9/11:
  - 2008 US National Ac. of Sciences report to Congress: Replace Am-Be neutron source with generator (switchable) or Cf-252 (safer source)
  - Government/agency initiatives: 2015 USDOE Scoping Study (LLNL TR-679101); 2018 UK Workshop

- US National Labs/Ukraine Ac. Sci.: Novel nucl. hardware

Alt-tech as Replacement
Requirements

- Accuracy (e.g.,: ±1 pu in porosity)
- Reliability
- Operational compatibility (e.g.: logging speed)
- Survivability (> 175^0 C; > 25 kpsia; 1000G in LWD, etc.)
- Cost: Develop, deploy, & use
- Compatibility with 50-60 yr. legacy data?
- Usable in a diverse industry landscape?

State of Tested Alternatives: Nonnuclear and Nuclear

Non-nuclear Techniques

Parameter	Acoustic	NMR
Porosity[+]	±2-4 pu	±2 pu: can it improve?
Lithology++	Limited	No
Mineralogy++	No	No
Inapplicable in	Unconsolidated sands Major oil fields	Very low porosity; micro-pores & paramagnetics: Major fields
Gas	Yes	Yes
Mitigate legacy data issue?	No	No
Logging speed?	Standard (1800 ft/hr)	Wireline: 240 ft/hr
Cost	Moderate	High*
Additional	Anisotropy	Fluid type; Permeability indicator

+ Cs-137 density porosity accuracy: ± 1 pu

++ Am-Be provides this

* Complex technology: Unaffordable/unusable by small players.

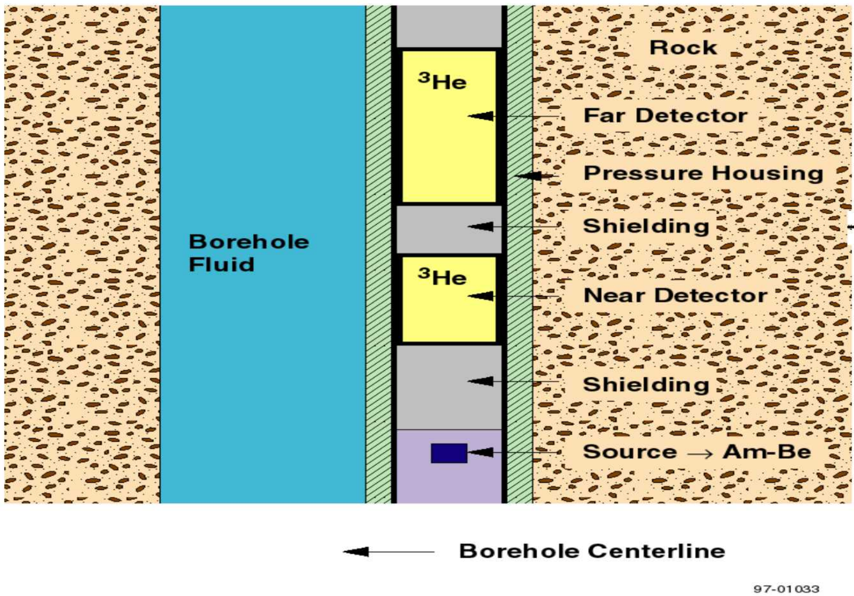
Tested Nuclear-based Alternatives to Am-Be Neutron Porosity Tools

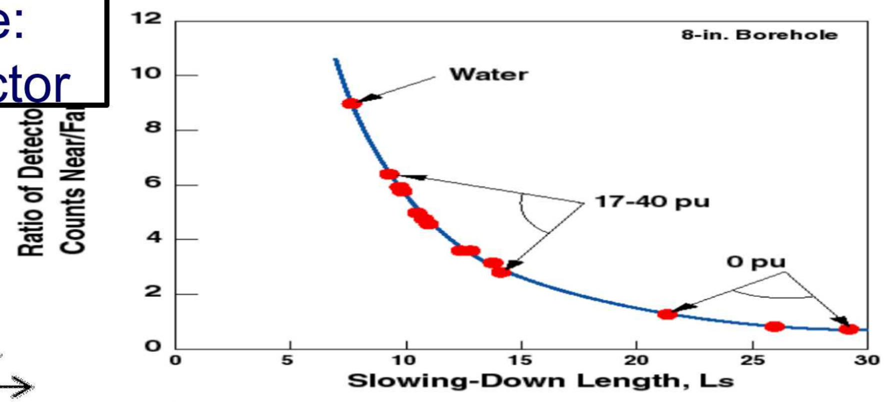
Basics of Neutron Porosity Measurement with an Am-Be Source

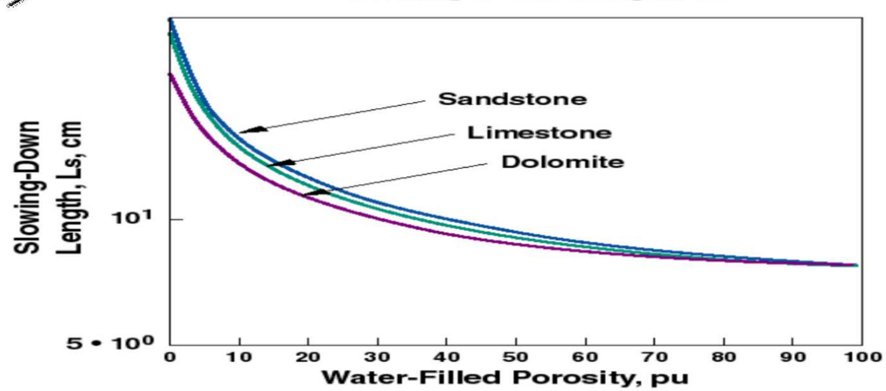
(Badruzzaman, 12th Biennial American Nuclear Society RPSD Topical Meeting, April 15-18, 2002, Santa Fe, NM)

Physics & Interpretation

Dual-detector Wireline neutron device: Am-Be source; some are single detector



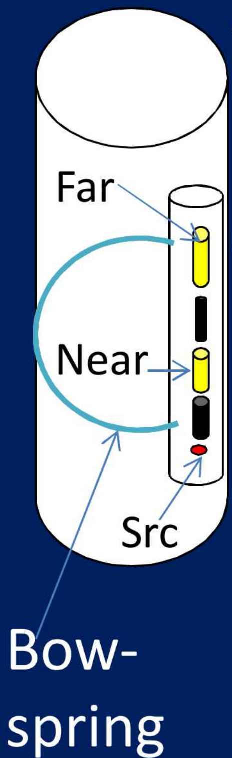




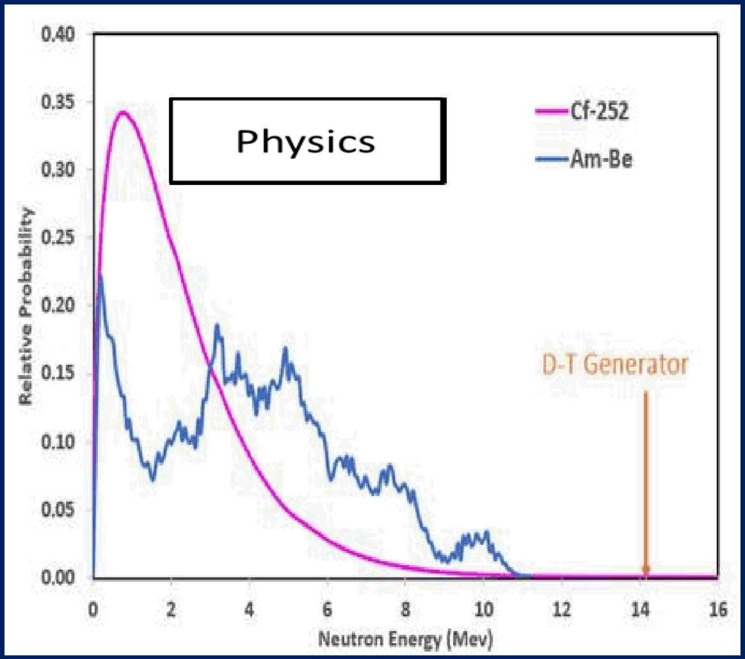
- Record total counts in each detector
- Dual-detector: Near/Far Ratio ⟶ Neutron slowing down or migration length → "Thermal Neutron Porosity"
- Single detector: Counts → Correlation

Not a pure porosity- affected by gas, clay, etc.
A Hydrogen index measurement, essentially

Tested Am-Be Source Alternatives



- US National Ac. of Sciences recommendation (2008): Use D-T generator (switchable) or Cf-252 (lower risk)
- :



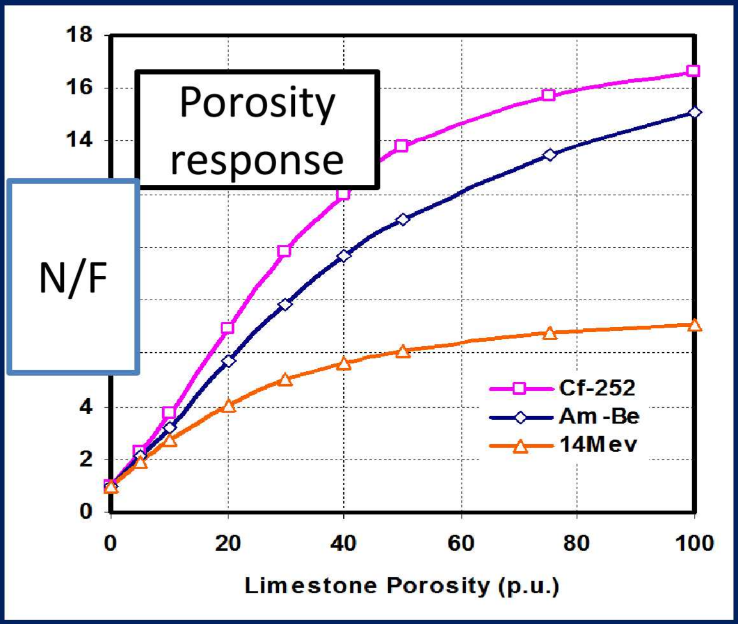


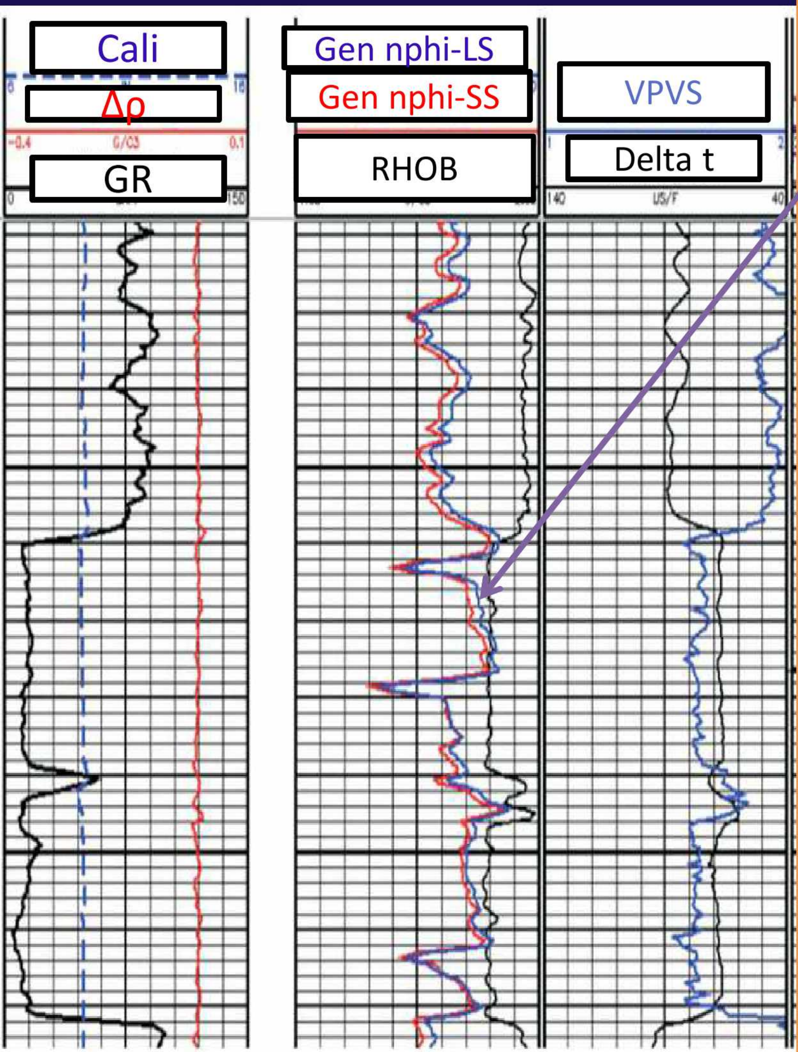
Figure: Xu et al, *Petrophysics,* June, 2010

- Industry had tested these concepts

❑ LWD tool (2000): acceptable; Wireline tool (1991): often poor

EX-1: Marketed wireline D-T generator neutron tool in wet sandstone: This tool uses only epithermal counts ratio used

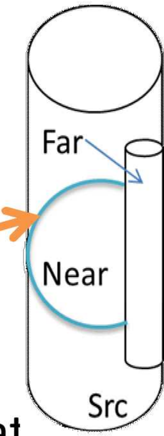
(Fig. Badruzzaman, Petrophysics, **46**, 2005)



Spikes in neutron in clean sand?

interpretation, design, operation?

Variable standoff likely: Bow-spring??



Standard correction failed

Epithermal neutrons: Standoff effect great

⇒ Vendor fix: Algorithm to get Am-Be-like thermal neutron porosity (2008)

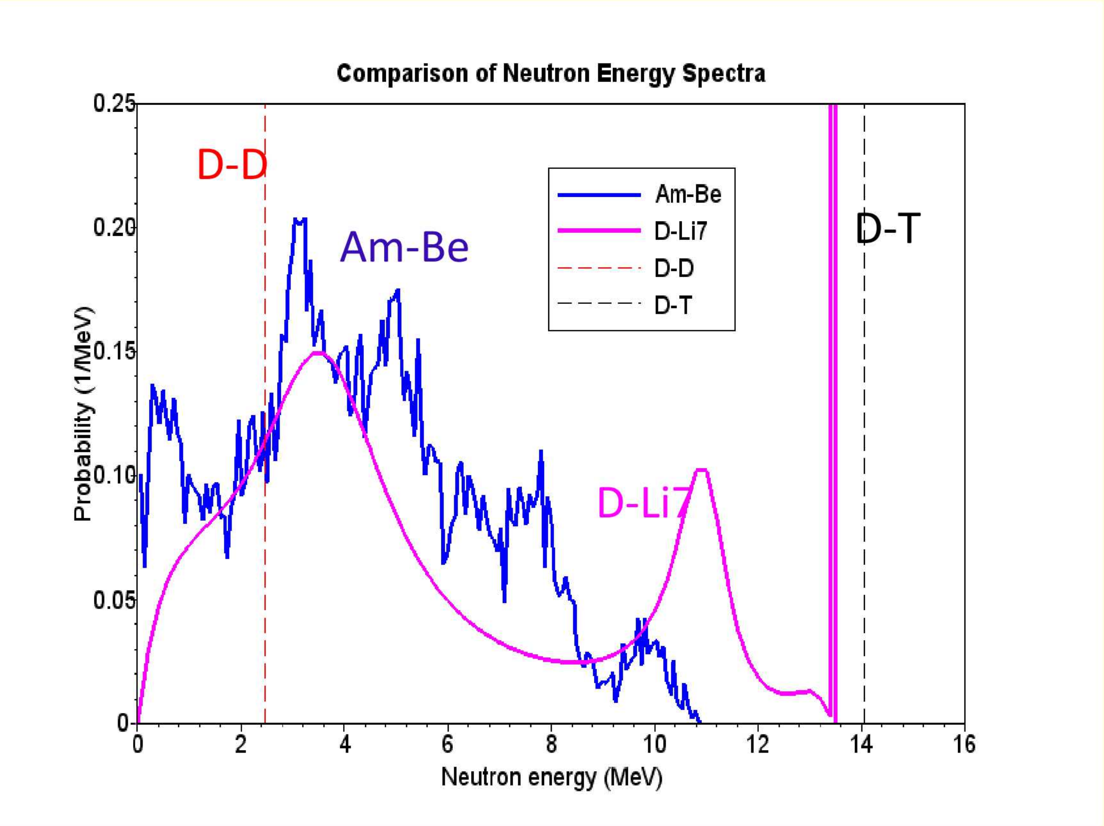
Re-tested tool: Fix mixed- still epithermal: ID'd a marker

This Study

Untested Promising Neutron Generators Vs. Am-Be and D-T

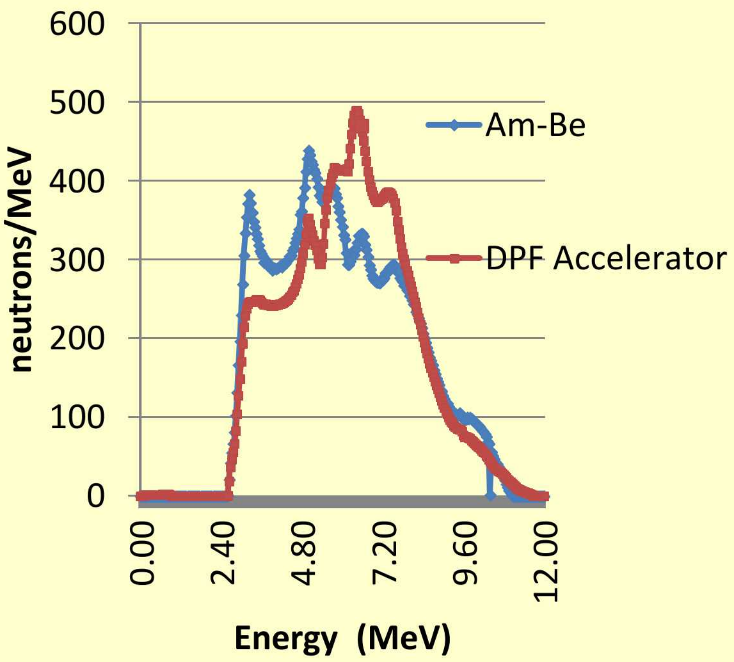
(Badruzzaman et al., Paper EEEE, SPWLA 58th Annual Logging Symposium)

Fusion Generators (nearer term)



DPF α-Be accelerator: Am-Be physics

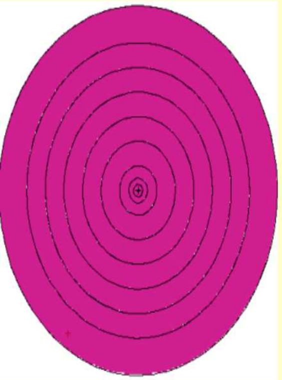
(Long term)

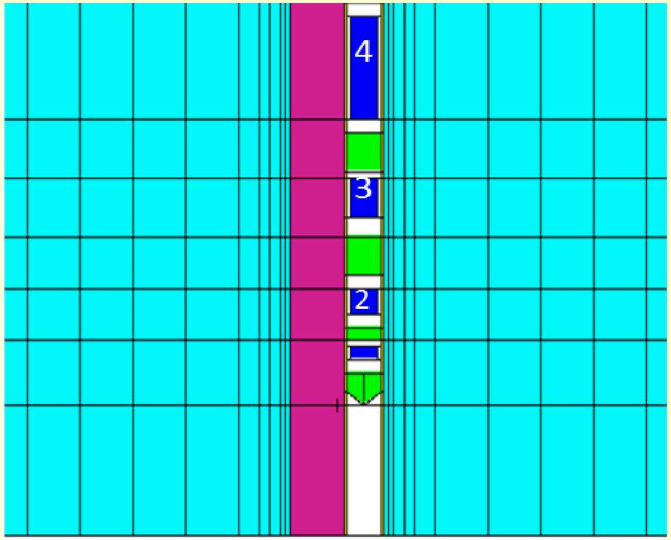


- Proximity to Am-Be spectrum ⟹ proximity to Am-Be porosity
- Neutron yield of generator ⟹ statistics & logging speed.

Present Study: Monte Carlo Simulation

- **Sphere & full tool-BH-Formation Models**: Analog (No variance reduction technique used); Unit s

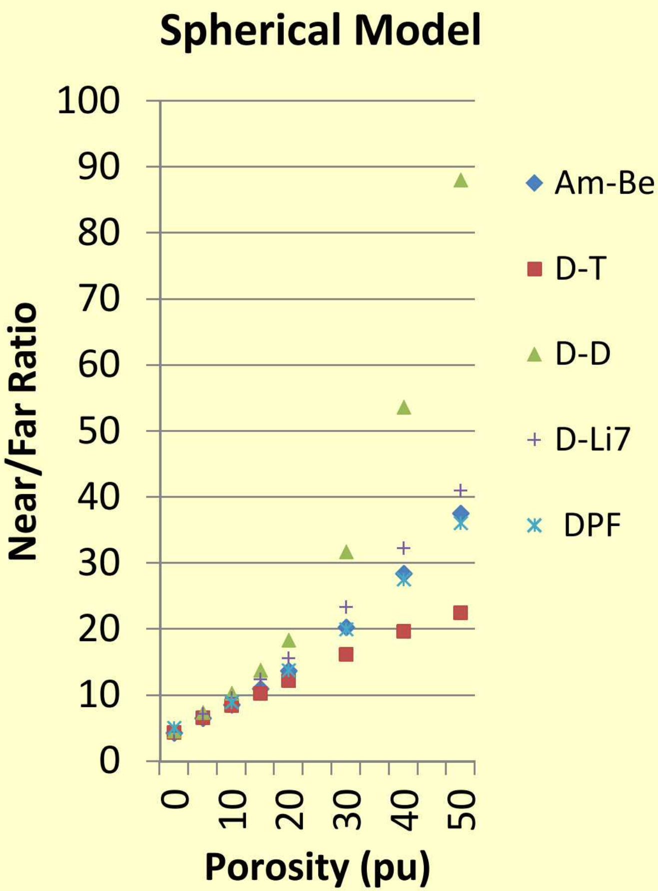


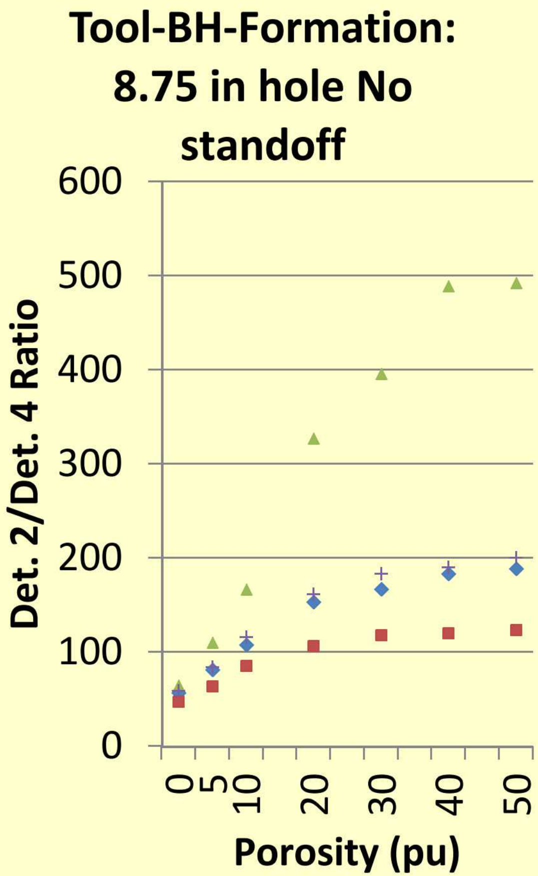


Condition	Sphere	Full Tool-BH-Formation
Basic Ratio Porosity Response	Yes	Yes
Low Porosity	Yes	Yes
Absorber	Yes	Yes
Standoff	No-Analytical model	Yes
Bit Size	-	Yes

- **Comment on source properties and spectroscopy aspects**

Basic Porosity Response-Near/Far* Ratio of Total flux





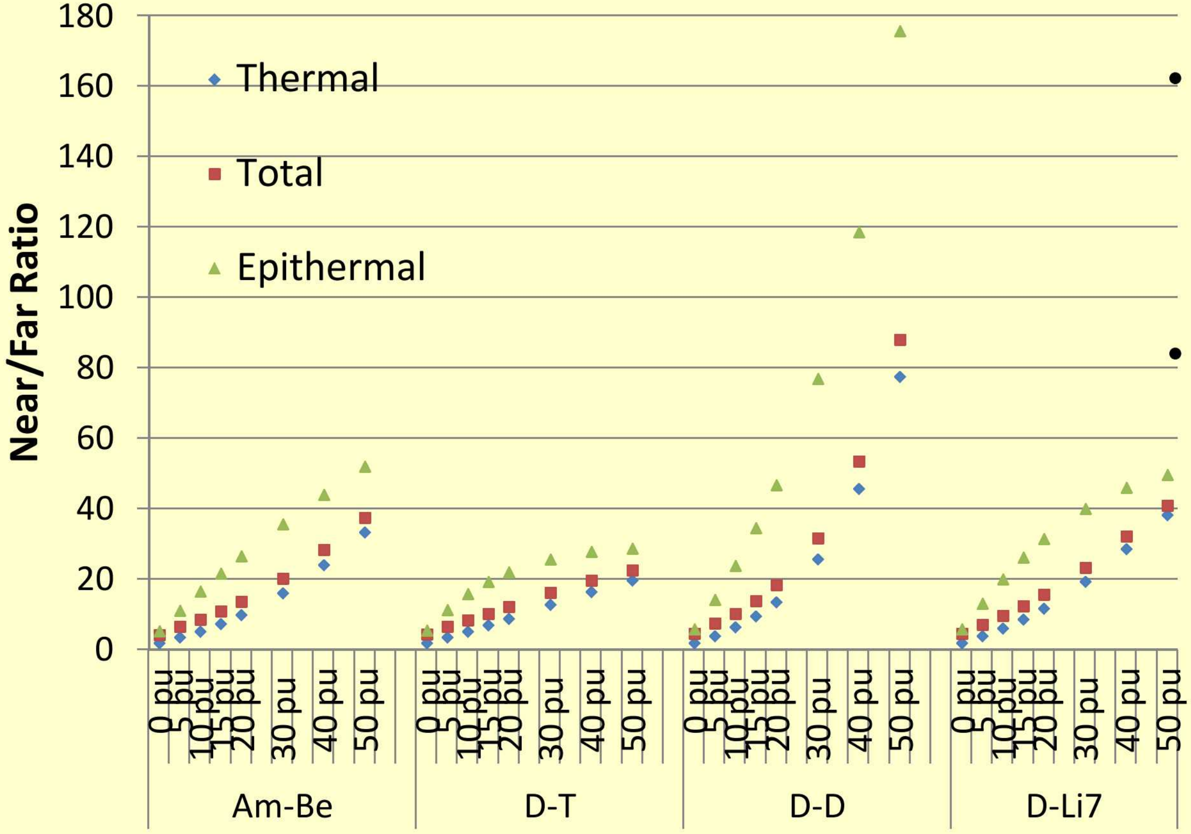
- D-D most sensitive, D-T least sensitive (known)
- DPF almost identical to Am-Be: *Is it a surprise?*
- D-Li7 similar to Am-Be
- Look at effect of borehole

Next slide: Look at Epithermal and Thermal flux ratios vs. Total

* Sphere: Near and Far are at 10 in 22 in

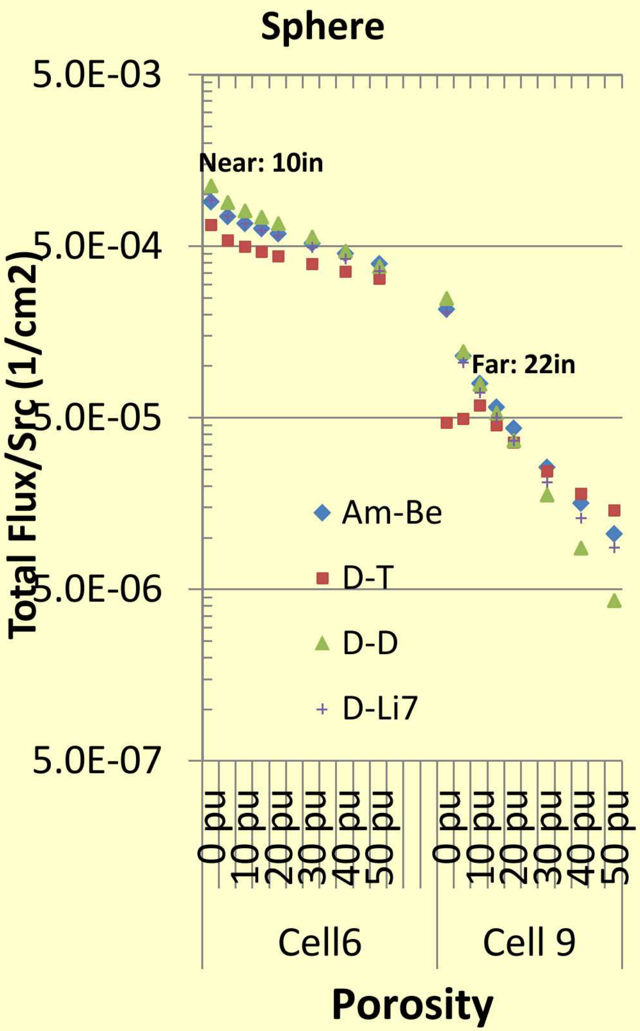
Total, Epithermal & Thermal Flux Ratios: Spherical Model

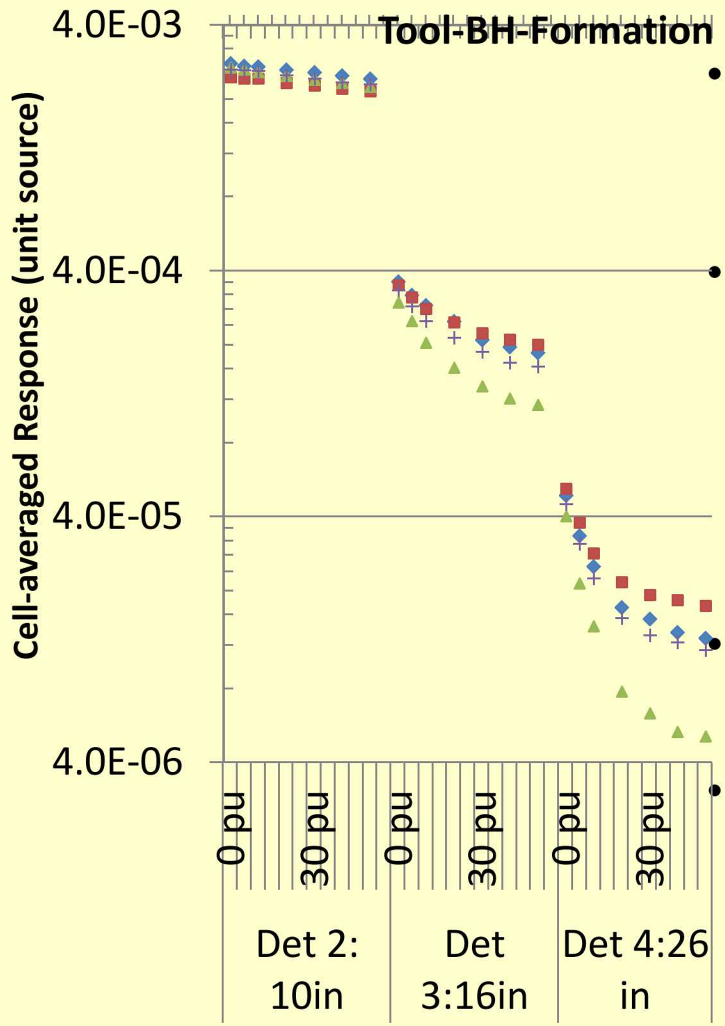
Near:10 in, Far:22 in



- Total Ratio and Thermal Ratio similar shape: Usual ratio porosity *denoted as 'Thermal Neutron' porosity?*
- Epithermal Ratio has a different shape:⇒ ***Will not easily replicate Am-Be response***

Near and Far Flux (per unit source)





- Near flux similar for all sources in this set-up
- Far flux vs. porosity in general is lowest for D-D: Cause of high N/F ratio and greater porosity sensitivity for DD.
- $\Rightarrow$ Poorer statistics slower logging speed
- *What could compound it further?*

Table 1. Source Properties: Typical Neutron Yields

Neutron Source	Nominal Yield (n/sec)
Am-Be Source	$2\text{-}4 \times 10^7$
D-T Generator	1×10^8
D-D Generator	1×10^6
D-Li7 Generator	1×10^6
DPF Accelerator$^+$	1×10^7

$^+$Estimate based on kinematic modeling

- DPF & Am-Be same order of magnitude
- D-T yield is highest
- D-D and D-Li7 ~50-fold lower vs. Am-Be and 100-fold lower vs. D-T
- Lower neutron yield ⇒ Further compound low D-D far counts. ⇒Unacceptable logging speed
- Impact of lower neutron yield from D-D combined with lower Far counts seen in D-D tool model
- Can neutron yield of fusion generators be increased?

Table 2.
Beam Power required by fusion generators studied to produce 2 x10^7 n/s*

Incident Particle Energy (keV)	Generator Beam Power (Watts)		
	D-T	D-D	D-Li7
100	0.03	8	1
150	0.02	5	1
200	0.02	4	1

* Similar to an Am-Be logging source

Comments:

D-T: Has several curies of Tritium

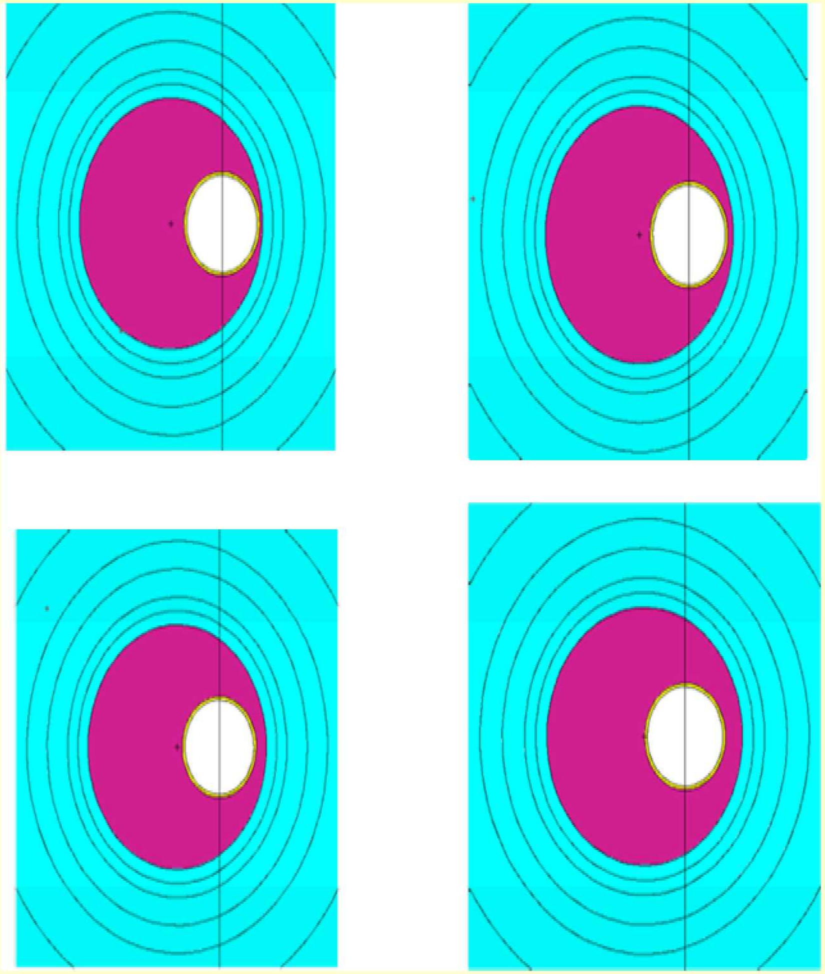
D-Li7: Less ideal target. Melting point of lithium is low; lithium compounds would further reduce yield.

D-D: - No Tritium

- A commercial RF-Based generator with ~5 x10^7 n/s is available, but..
- Research underway to increase neutron yield in a compact generator

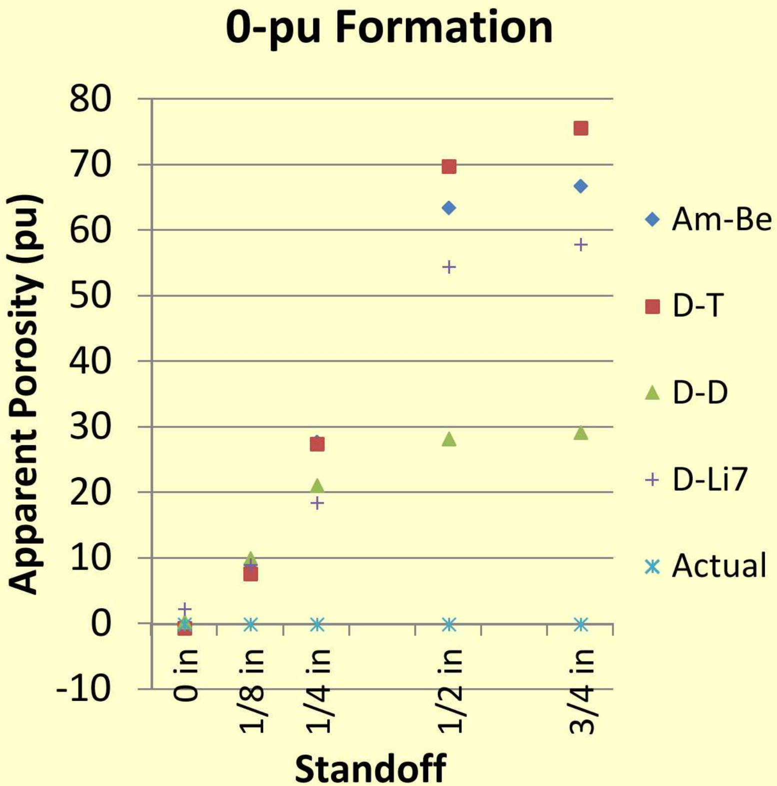
Standoff Effect

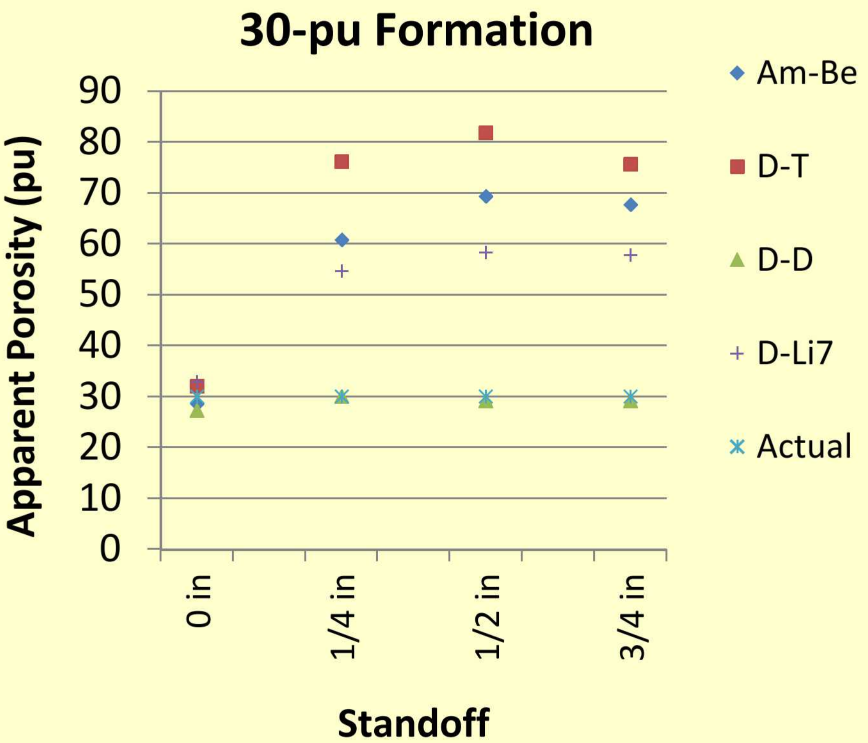
Tool-BH-Formation Model-Standoff Variation



- Note how the Hydrogen volume neutrons see increases with standoff increase
- Will standoff effect be source-dependent?
- Is the magnitude of the effect porosity-dependent? *Considered 0-pu and 30-pu*
- Is there an effect of the Hydrogen Index contrast between formation and the standoff next to it?

Tool-BH-Formation Model-Standoff Effect





- Standoff can have a large effect. D-D neutron-predicted apparent porosity least affected and D-T is most.
  - ➢ Epithermal porosity would be affected more than Total counts porosity
- Am-Be and D-Li7 effects are similar, D-Li7 being somewhat less affected at high porosity.
- Standoff effect is porosity-dependent
- Standoff effect is Formation vs. Standoff HI Contrast-dependent

⇒ **Will be difficult to correct using neutron physics-based tricks proposed. Need an ultrasonic caliper to quantify standoff?**

Summary: Neutron Generators Vs. Am-Be Tradeoffs

Attribute	DPF	D-T	D-D	D-Li7
Porosity sensitivity	Almost identical	Less: design a longer tool?	Greater,	Similar
Low porosity Response	Likely Similar	Similar	**Greater- Usable?**	Greater – Usable?
Th. absorber sensitivity	Would be Similar	Less - Complex	**Greater – Correctable?**	Similar
D.O.I	Similar	**Greater**	??	Likely similar
Standoff effect	Similar	**Greater**	**MuchLess**	Similar
Am-Be equivalence	Similar	A complex algorithm	**Less complex vs. D-T**	Similar
(n-ɣ) Spectroscopy	Similar: Capture	**Inelastic & Capture**	Capture only	Inelastic & capture
Logging Speed	Similar?	**Can be faster**	**Slower- but..**	Slower
Source Adaptability	Needs long term R&D	**Industry experience;** T^3 radioactive	Likely with research	Challenge

A Question: Options to Replace Am-Be for Logging?

- Non-nuclear options would not suffice

- No magic bullet with generators- Would require tradeoffs

⇒Move forward with current, apparent D-T-only path?

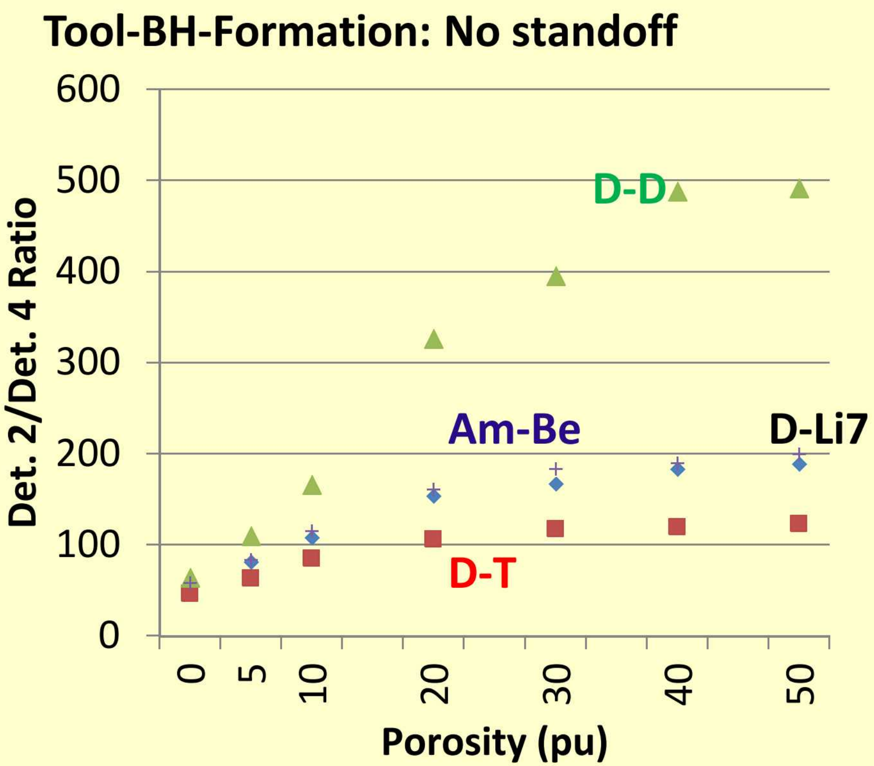
Or

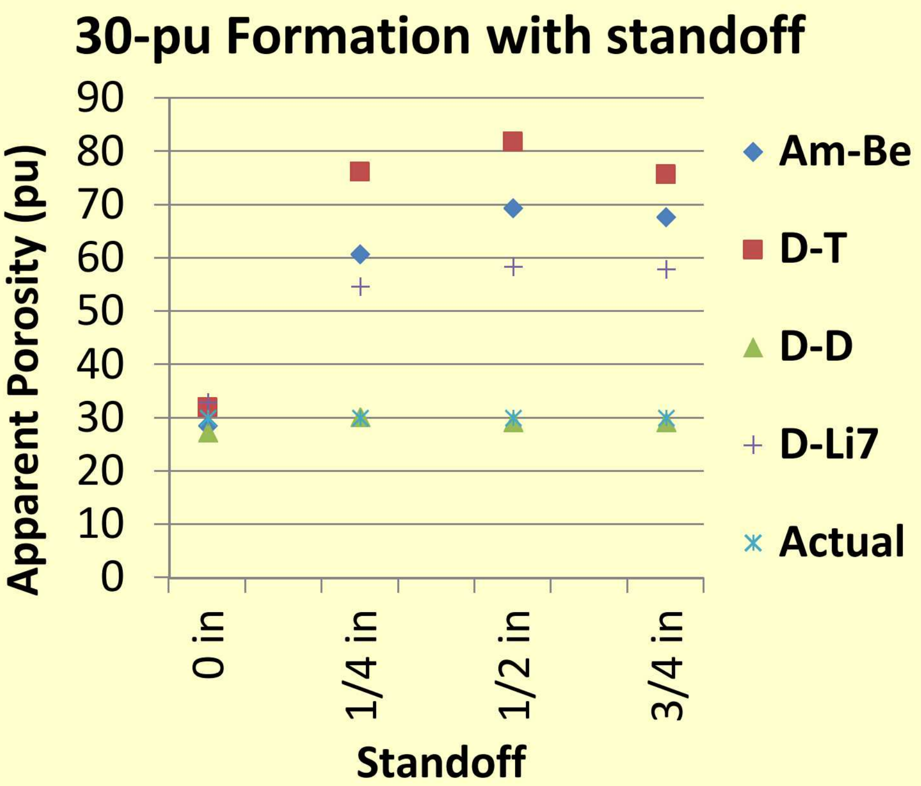
⇒Use a combination of generators?

  - ➢ If yes, what will that be?

Porosity Response-Near/Far Ratio of Total flux

Badruzzaman, Schmidt, and Antolak, SPWLA 58th Annual Logging Symposium, Paper EEEE





- D-D most sensitive,
- D-T least sensitive

- Standoff effect large
- D-D: least affected
- D-T: most affected (As in field example)

- *R&D continues: 4 Test D-D neutron tools under design*

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