Importance and Role of Isotopes in the Petroleum Industry

Eric L. Rosemann, CSP

Chairman of the Subcommittee for
Radiation Safety and Security
for the Association of Energy
Service Companies (AESC)

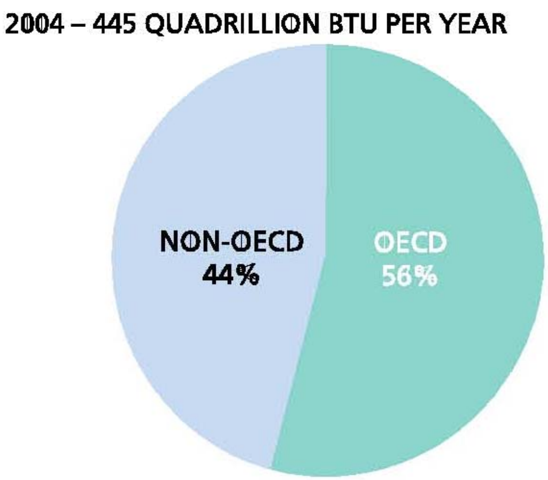
Terms

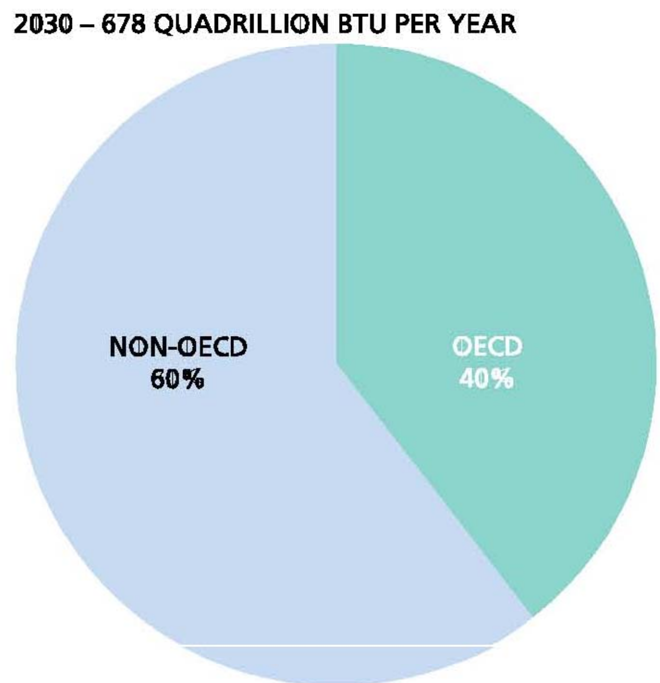
- **Logging** – the process of taking geophysical and other wellbore measurements using electrical, magnetic, acoustic, nuclear and mechanical means and can be performed during or after drilling operations or both.
- **Open Hole** – freshly drilled well held open by the weight of the drilling fluid
- **Cased Hole** – casing pipe that is cemented into place after drilling to hold the well open
- **Tubing** – removable smaller pipe that is used for the actual production of the oil and/or gas
- **Production formation** – usually Sandstone, Limestone, Dolomite and certain Shales
- **Porosity** (includes fractures and other voids) – the space between the solid formation materials that can hold oil, gas, water and/or clay

The Petroleum Industry Contribution to the Nations Energy Needs: Past, Present and Future

AESC

World Energy – Anticipated Demand though 2030

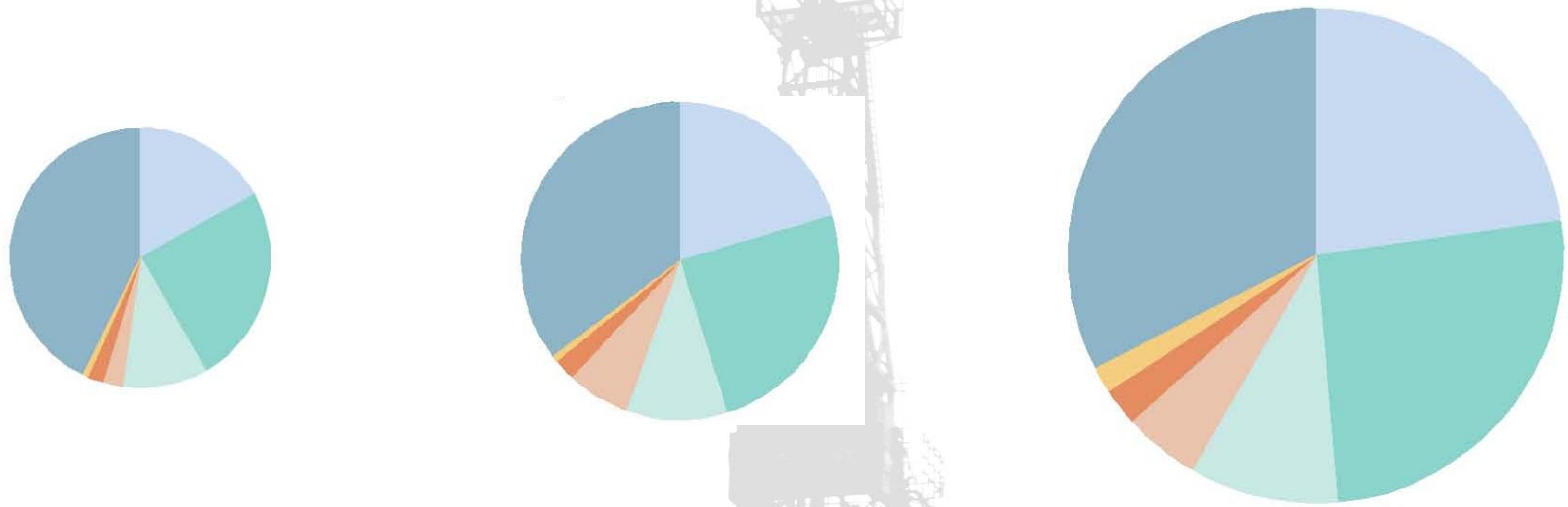




Source: IEA *World Energy Outlook 2006.*

National Petroleum Council Report
Facing Hard Truths - 2007

World Energy Supply – Historical and Predicted through 2030



1988
288 Quadrillion BTU/Yr.

2004
455 Quadrillion BTU/Yr.

2030
678 Quadrillion BTU/Yr.

OIL
GAS
COAL
BIOMASS
NUCLEAR
HYDRO
WIND/SOLAR/ GEOTHERMAL

Data Source: IEA World Energy Outlook 2006.

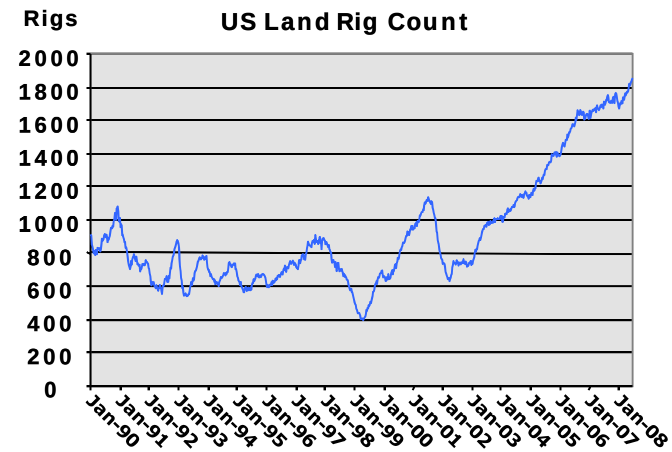
National Petroleum Council Report
Facing Hard Truths - 2007

The Logging Business is a vital part of every well!

- Every Well requires formation evaluation, logging is a key part of this evaluation.

- The quality and accuracy of data is key to decide and ascertain if the well is a producer or dry hole

- This evaluation supports and drives:
  - Production estimations,
  - Well economics,
  - Reserve calculations,
  - Corporate and Gov. energy assets,
  - Overall market fundamentals



Forecast - Drilling	2008	2009	% WW
Spot WTI ($bbl)	$ 114.81	$ 120.00	
Spot Gas Price	$ 9.26	$ 9.50	
Rig Count			
US	1,870	1,980	51%
Canada	361	406	
International	1,077	1,141	
Russia	352	370	
China	n/a	n/a	
Total	3,660	3,897	100%
Wells Drilled			
US	59,789	62,724	51%
International	18,049	20,223	
Russia	13,666	14,332	
China	18,592	19,324	
Total	115,250	122,003	100%

Source: Spears and Ass. – DPO June 08

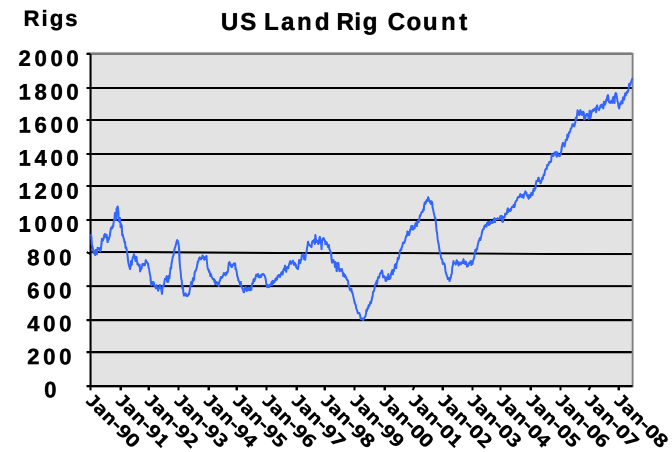
The Logging Business is a vital part of every well!

- Supports ability to commit to long term projects with less than certain payback.

- Provides support for filing Company's statement of reserves.

- Helps value royalty payments back to state and federal government and drives legislation.

- The US is most affected:
  - ½ of worlds activity
  - ¼ of world consumption
  - < 5% of world reserves
  - greatest need for immediate continuity of supply



Forecast - Drilling	2008	2009	% WW
Spot WTI ($bbl)	$ 114.81	$ 120.00	
Spot Gas Price	$ 9.26	$ 9.50	
Rig Count			
US	1,870	1,980	51%
Canada	361	406	
International	1,077	1,141	
Russia	352	370	
China	n/a	n/a	
Total	3,660	3,897	100%
Wells Drilled			
US	59,789	62,724	51%
International	18,049	20,223	
Russia	13,666	14,332	
China	18,592	19,324	
Total	115,250	122,003	100%

Source: Spears and Ass. – DPO June 08

How Big is the Logging Business?

Wireline Logging

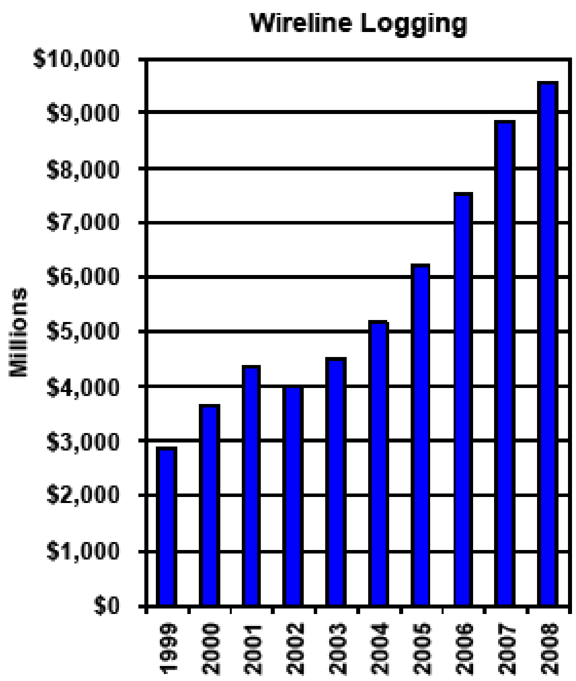
15% compound annual growth

Wireline logging includes both open hole and cased hole services. Open hole logging occurs during the drilling process and usually measures characteristics of the rock and the fluids and gases contained therein. Cased hole logging occurs in both new and old wells. Whether in new or old wells, wireline logging includes acquiring data from downhole and interpreting that data to help the operator decide what action to take next. Wireline logging includes formation and production logs run off slick line units.

This is a market segment that was threatened in the 'Nineties by its sister technology, Logging-While-Drilling (LWD). LWD ate into the openhole logging market offshore, shrinking the available dollars in this space, but LWD reached saturation earlier this decade and wireline logging is again growing with global rig count.

Wireline Evaluation Logging Market ($B)

	North American	International	Total
Open Hole	$1.2	$2.4	$3.6
Cased Hole	$2.6	$2.6	$5.2
Total	$3.8	$6.0	$8.8



Source: Spears and Ass. – OMR 2007

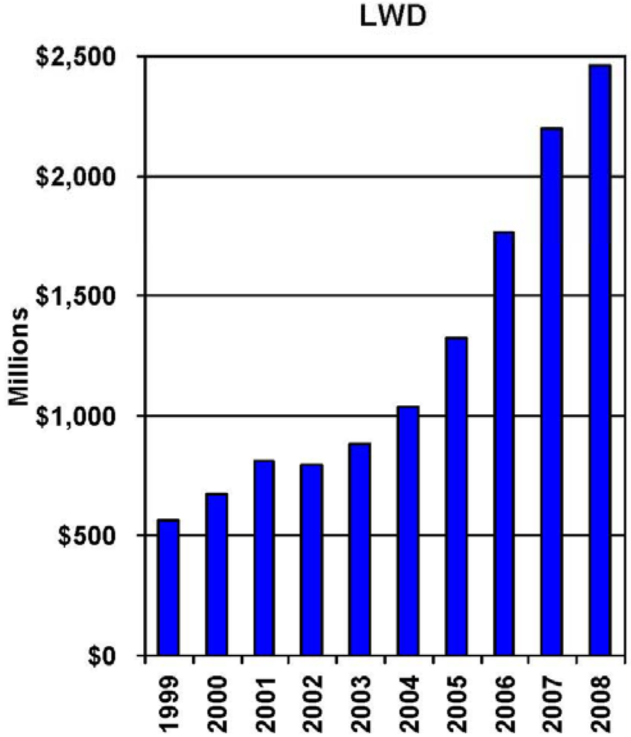
How Big is the Logging Business?

Logging-While-Drilling

18% compound annual growth

Logging-While-Drilling (LWD) includes all formation evaluation measurements conducted while drilling. This $2.2 billion market has been growing at >25% per year even though rotary steerable technology – RST – drills faster and takes away drilling days, generating less revenue per job.

With the success of rotary steerable, a portion of the LWD market is threatened. RST is sold on a performance basis, charging effectively a high day rate, but LWD is still rented by the day. Offshore, where a well drilled with RST is drilled in half the time, LWD charges are half the size they used to be. Service companies have not been able to raise the LWD day rate, in fact, increasing competition has put downward pressure on day rates.



Source: Spears and Ass. – OMR 2007

Radioisotopes Usage in Formation Evaluation Measurements

Well Logging 101

Well Logging 101

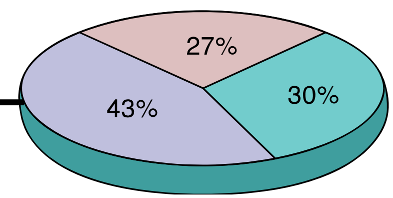
- Reserve Estimates and Archie – the math
- Well Logging – Vertical and Horizontal
- Density Logs – the Gold Standard for porosity
- Neutron Logs – more than just porosity
- Spectral Gamma Ray – clay is deadly to a well
- Frac-Tagging Operations – optimizing the completion
- Tracer and Production Logging – checking the health of the well
- Other Non-Logging Radioisotope Applications

Reserves Estimates and Archie – the math

Porosity

Producible Oil In Place

$$N_R = 7{,}758 \frac{AF_R}{B_o} \sum_{i=1}^{n} h_i \phi_i (S_o)_i ,$$



Saturation

Producible Gas In Place

$$G_R = 43{,}560 \frac{AF_R}{B_g} \sum_{i=1}^{n} h_i \phi_i (S_g)_i ,$$

Reserves Estimates and Archie – the math

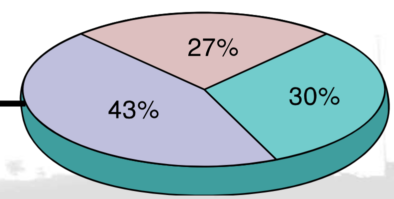
Producible Oil In Place

$$N_R = 7{,}758 \frac{AF_R}{B_o} \sum_{i=1}^{n} h_i \phi_i (S_o)_i,$$

Producible Gas In Place

$$G_R = 43{,}560 \frac{AF_R}{B_g} \sum_{i=1}^{n} h_i \phi_i (S_g)_i,$$

Porosity



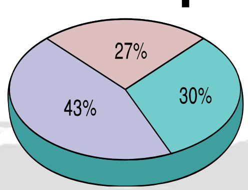
Saturation

Reserves Estimates and Archie – the math

Archie's Equation determines the water saturation for each zone being measured

$$S_w = \left(\frac{R_0}{R_t}\right)^{1/n} = \left(\frac{FR_w}{R_t}\right)^{1/n} = \left(\frac{aR_w}{\phi^m R_t}\right)^{1/n}$$

- **Where *Rt* is the formation resistivity from electrical and magnetic logs**
- ***Rw* comes from electrical and magnetic and near-by production**
- ***Φ* is the formation porosity from nuclear and acoustic logs**
- ***a, m* and *n* are empirically determined parameters**

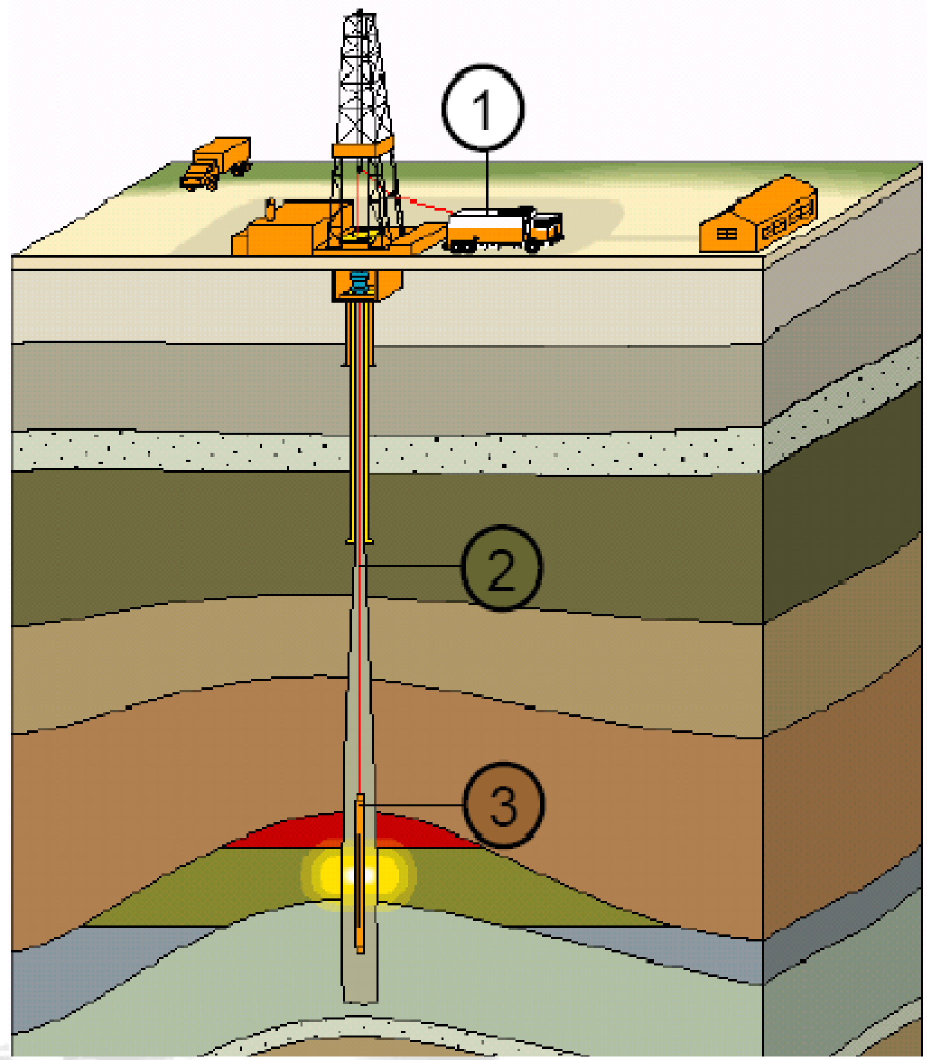


Saturation

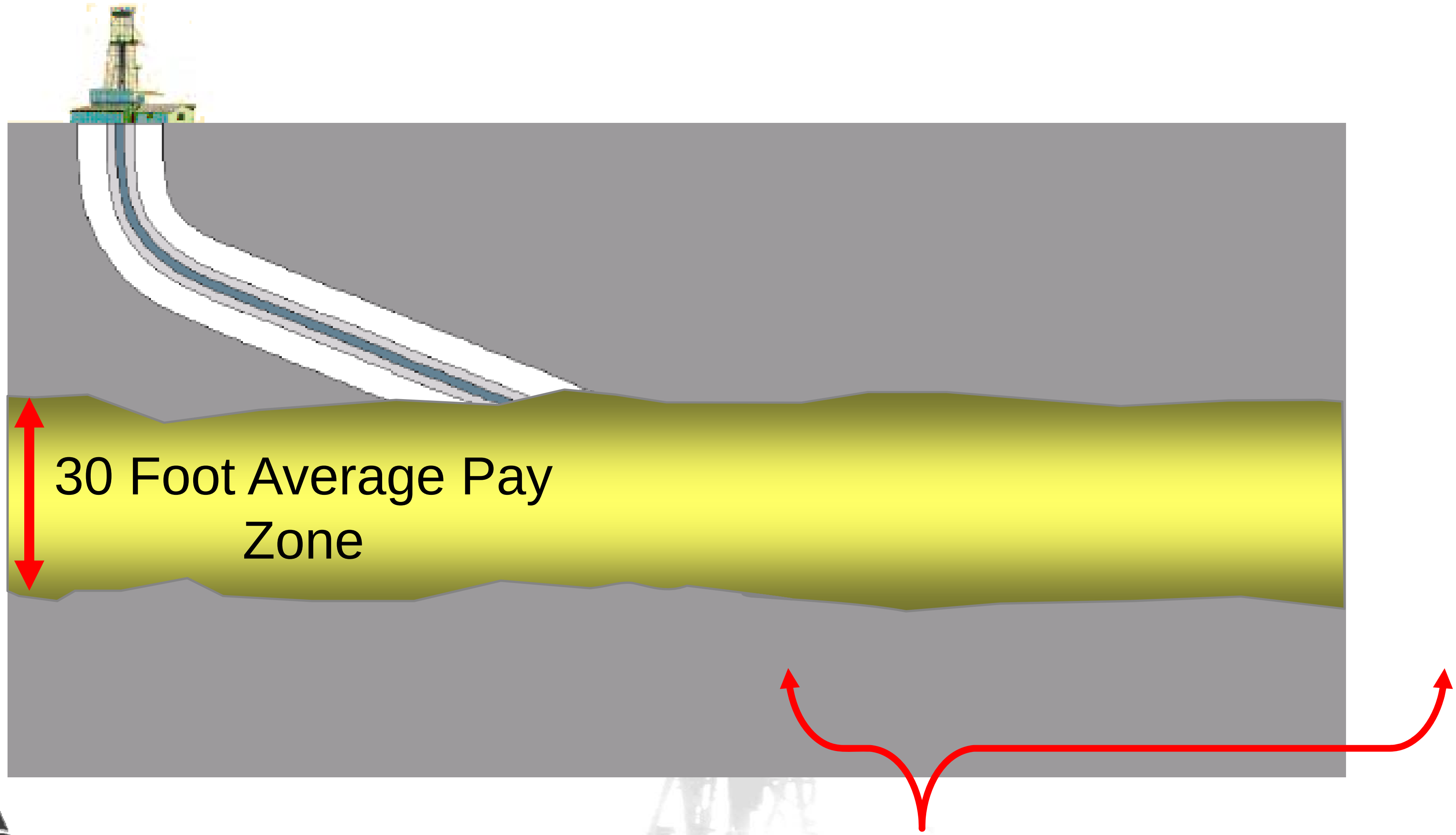
Porosity

Well Logging - Vertical

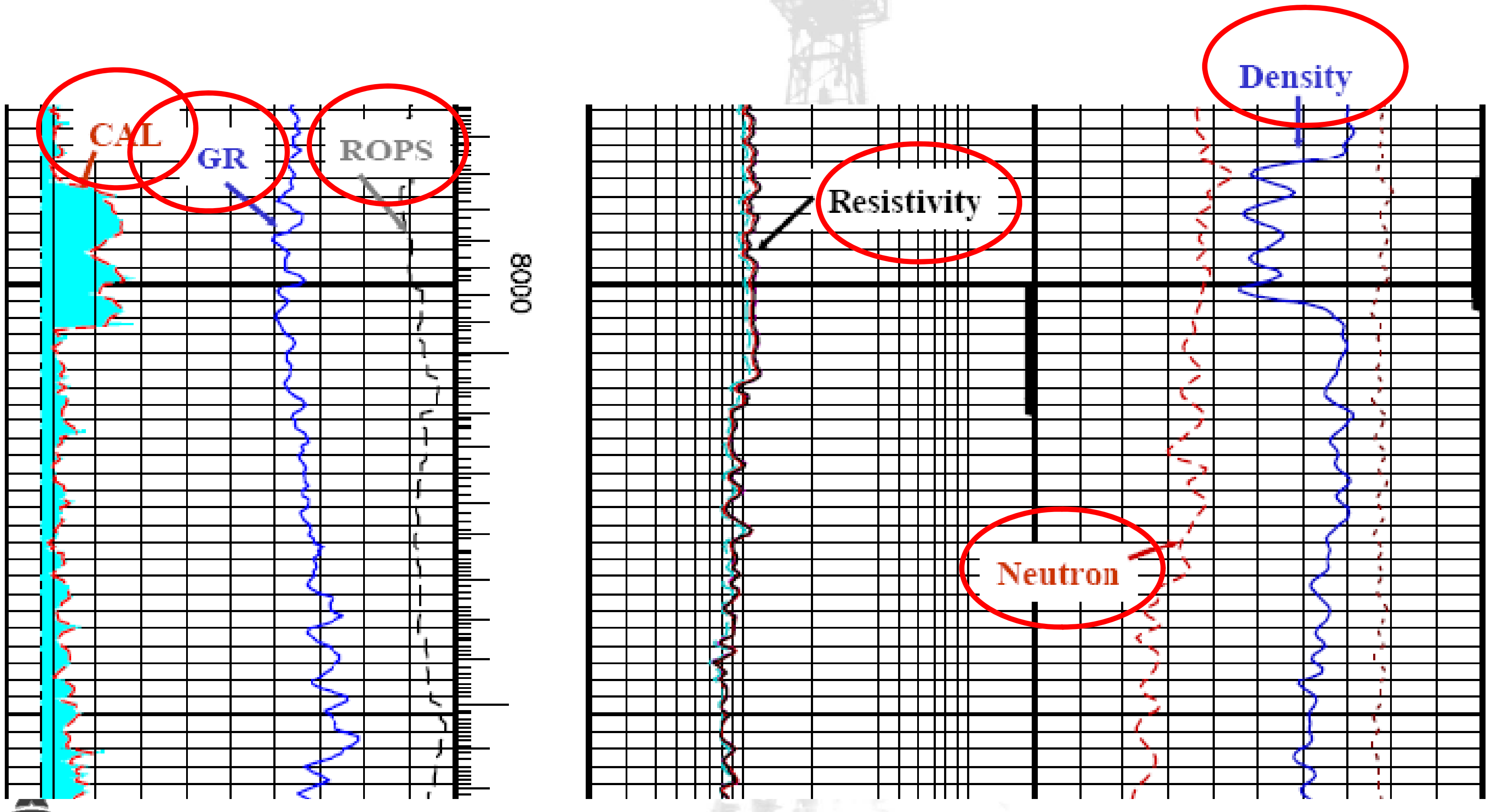
1. Data Recording Truck or Unit
2. Conveyance System
   - Armored Electrical Cable
   - Drill Pipe
3. Survey Instruments



Well Logging - Horizontal



Standard Log Presentation

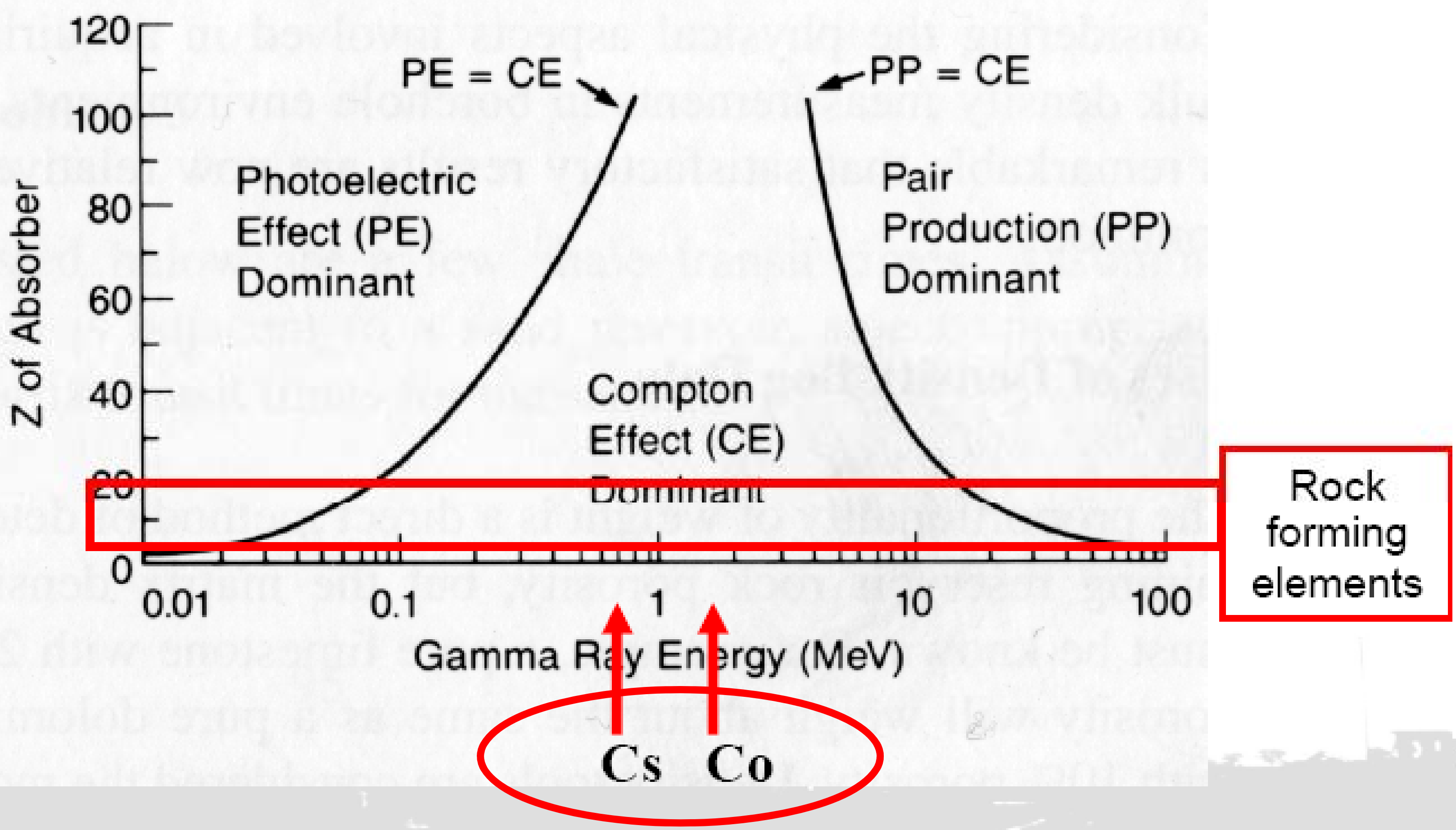


Density Logs – the Gold Standard for porosity

- Gamma-gamma density measurements depend on interactions between gamma rays and electrons or atomic nuclei within the formation
- Three types of interactions are important
  - Pair Production can occur at high gamma ray energies
  - Compton scattering dominates at moderate energies
  - Photoelectric effect has an influence at low energies
- Compton scattering is the most important of these three in gamma-gamma density measurements

Gamma Ray Absorption Mechanisms

In the energy range between 0.5 and 5 MeV
for most abundant elements the COMPTON-effect dominates.



Bulk Density and Electron Density

Gamma-gamma density tools actually respond to electron density rather than bulk density. Electron density is related to the number of electrons per molecule, ΣZ, and bulk density is related to the total atomic mass per molecule, ΣM. For most common Earth minerals, the ratio

$$\frac{\sum Z}{\sum M} \approx 1/2,$$

and thus

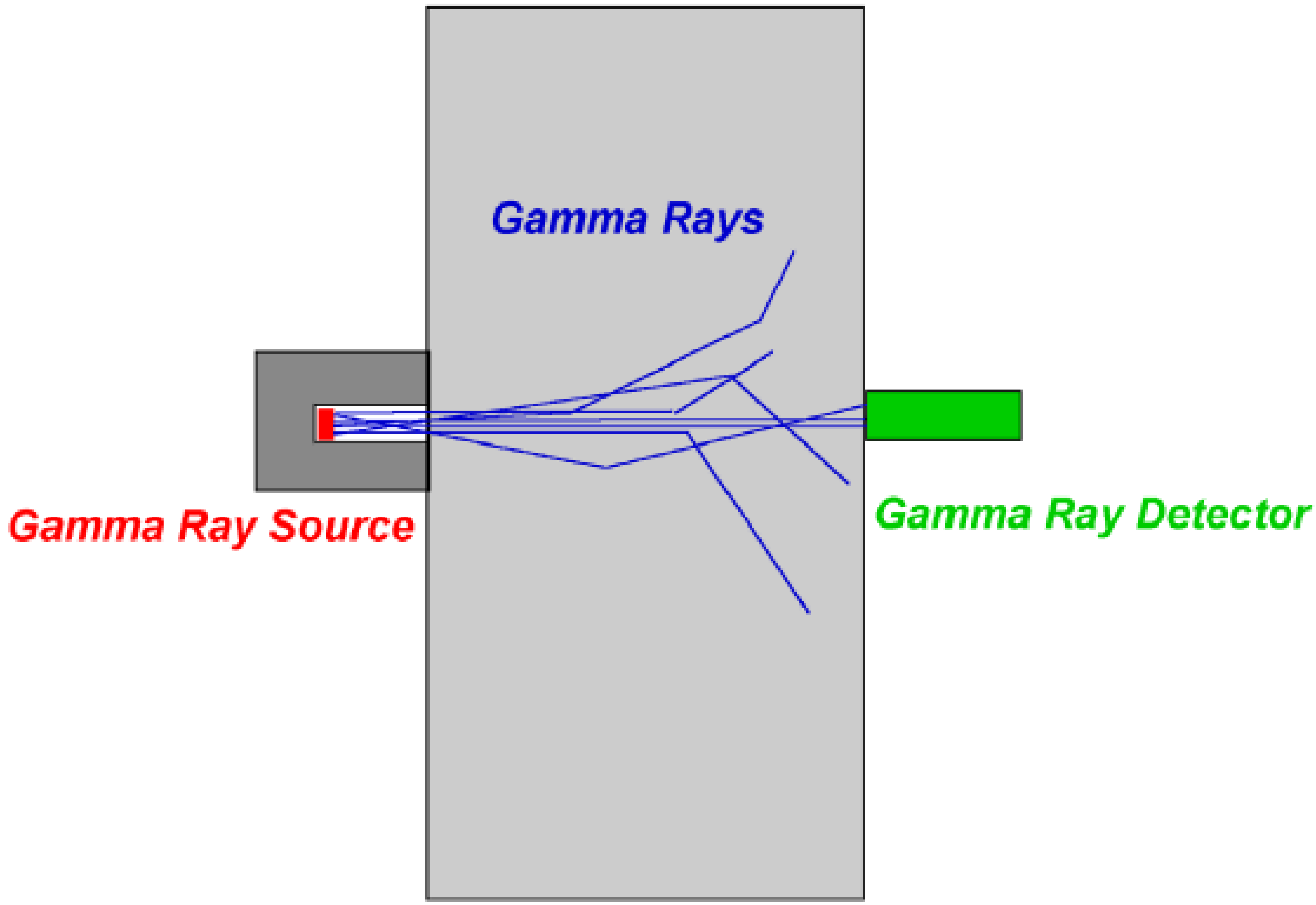
$$\rho_e = 2\frac{\sum Z}{\sum M}\rho_b .$$

Values for Common Materials

Charge-to-Mass Ratios, Mass Densities, Log Response Densities, Photoelectric Absorption Index Values for Materials Commonly Found in Boreholes

Material	Chemical Formula	$\Sigma Z/\Sigma M$ (charge/amu)	ρ (g cm^{-3})	ρ_b (g cm^{-3})	Pe (b/e)
Quartz	SiO_2	0.499	2.65	2.64	1.806
Calcite	$CaCO_3$	0.500	2.71	2.71	5.084
Dolomite	$CaMg(CO_3)_2$	0.499	2.87	2.87	3.142
Montmorillonite (Smectite)	$(Na,Ca)_{0.33}(Al,Mg)_2 Si_4O_{10}(OH)_2 \cdot nH_2O$	0.502	2.06	2.02	2.04
Illite	$KAl_4(Si,Al)_8O_{20}(OH)_4(O,OH)_{10}$	0.499	2.64	2.63	3.45
Kaolinite	$AL_2O_3 \cdot 2SiO_2 \cdot 2H_2O$	0.504	2.59	2.61	1.83
Chlorite	$Mg_5(Al,Fe)(OH)_8(Al,Si)_4O_{10}$	0.497	2.88	2.88	6.30
K-Feldspar	$KAlSi_3O_8$	0.496	2.56	2.53	2.86
Plagioclase (Na)	$NaAlSi_3O_8$	0.496	2.62	2.59	1.68
Plagioclase (Ca)	$CaAl_2Si_2O_8$	0.496	2.76	2.74	3.13
Barite	$BaSO_4$	0.446	4.48	4.09	266.8
Siderite	$FeCO_3$	0.483	3.94	3.89	14.69
Pyrite	FeS_2	0.483	5.01	4.99	16.97

A Simple Lab Experiment



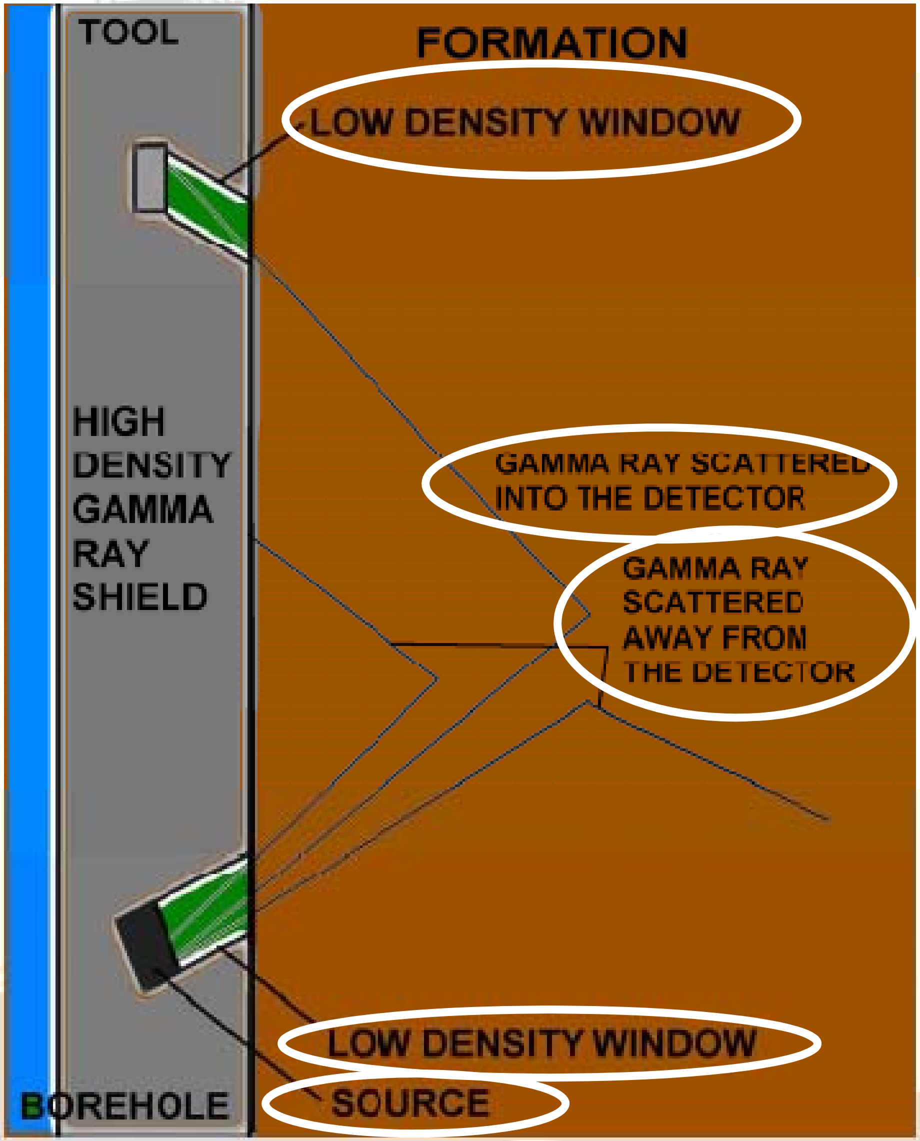
Single Detector Gamma-Gamma Density

Gamma Ray

Absorption, or

Gamma-Gamma

Density Logs

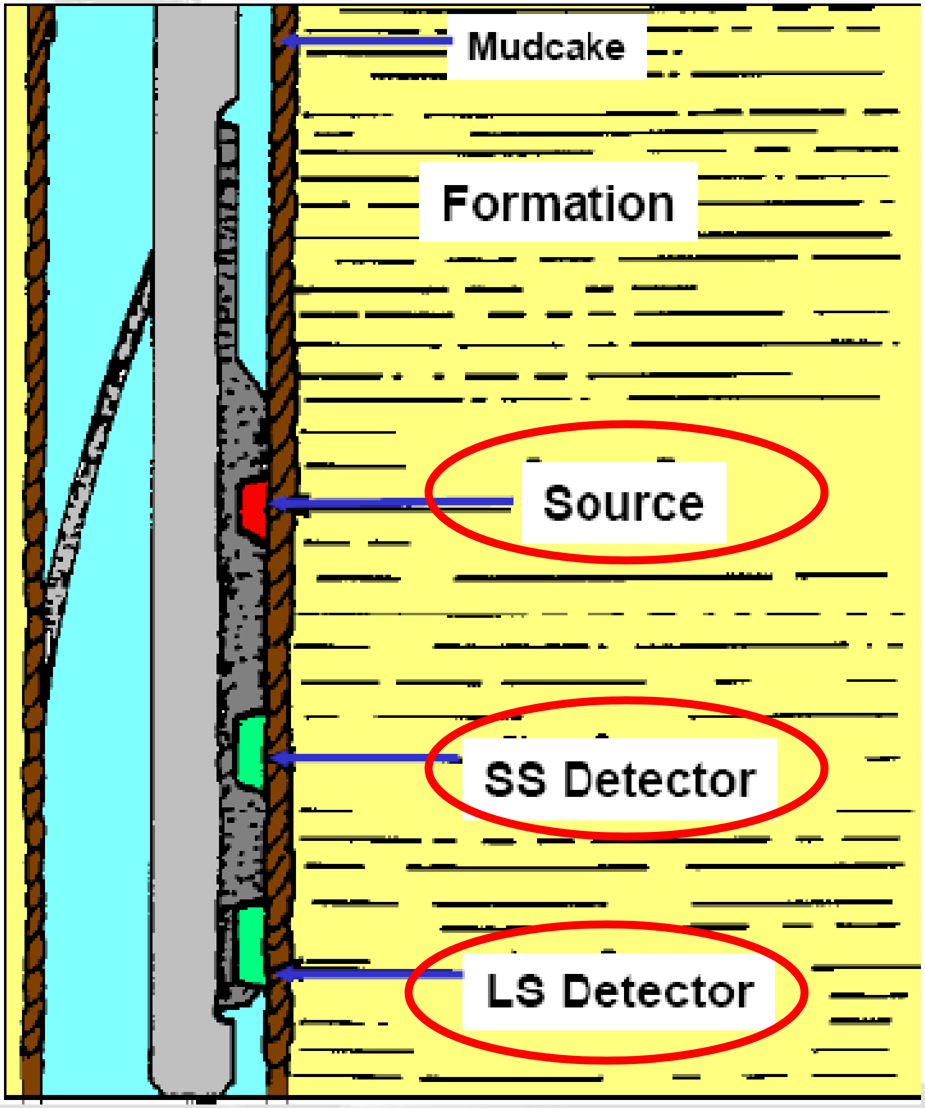


Dual Detector Wireline Density Tool

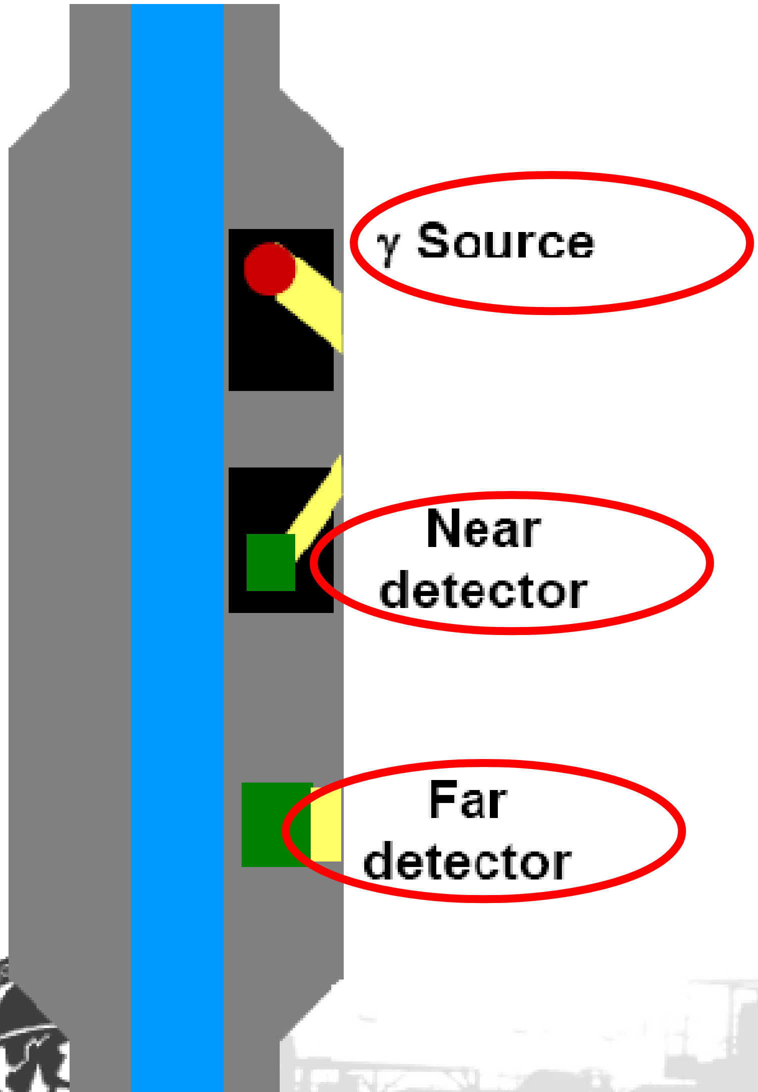
Typical instrument configuration:

NaI detectors

Source	Cs^{137}
Strength	~2.5 curie
GR Energy	662 keV



A Dual-Detector MWD Density Tool



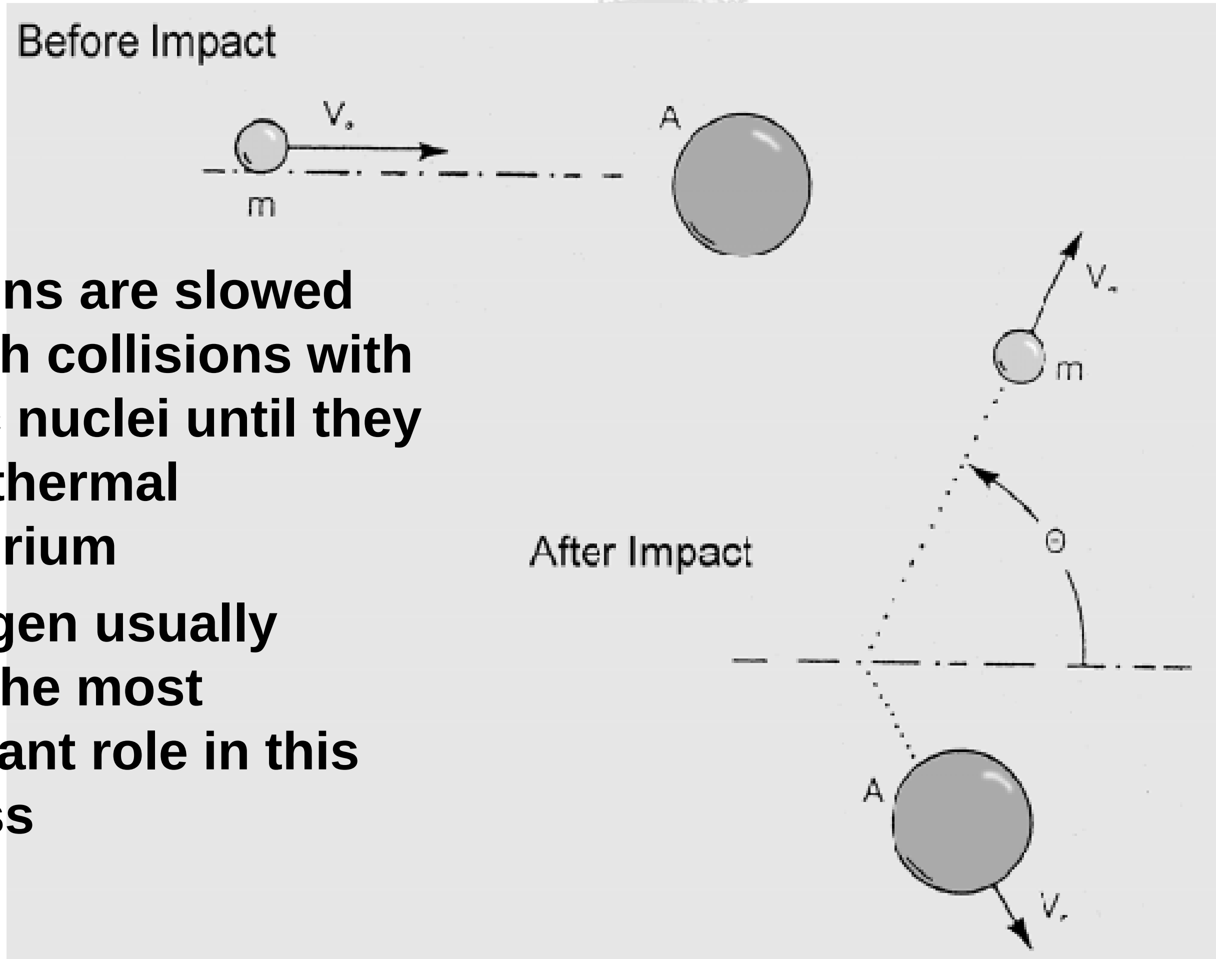
- "Fluid displacer" to bring detectors closer to the formation.
- Collimated source and detector windows
- Tungsten shielding

Neutron Logging – more than just porosity

- Neutrons from the source enter the formation and lose energy, mostly by elastic (billiard ball) scattering
- Hydrogen, located in the pore space, normally plays the most important role in this process
- Porosity is determined from neutron counting rates
- Neutron and other measurements are used together for more detailed analysis

AESC

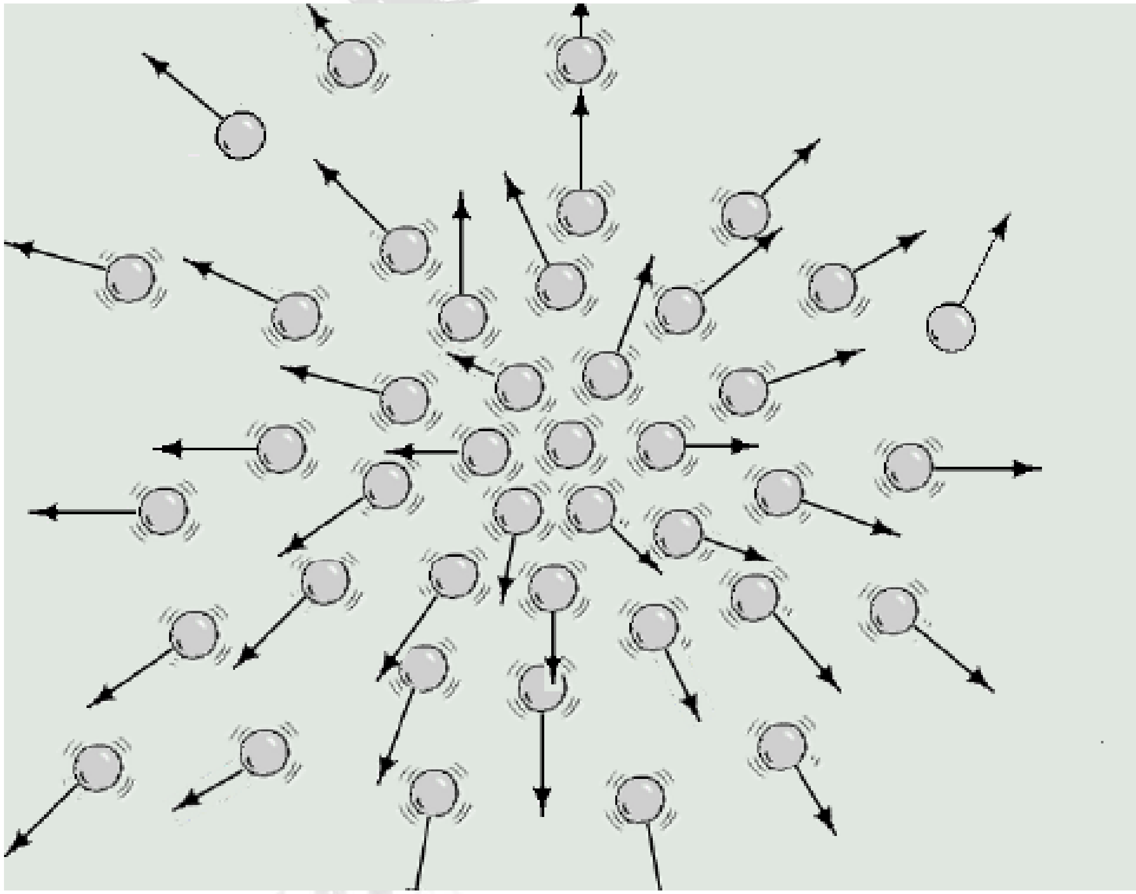
Elastic Neutron Scattering – "Slowing Down"



- Neutrons are slowed through collisions with atomic nuclei until they reach thermal equilibrium
- Hydrogen usually plays the most important role in this process

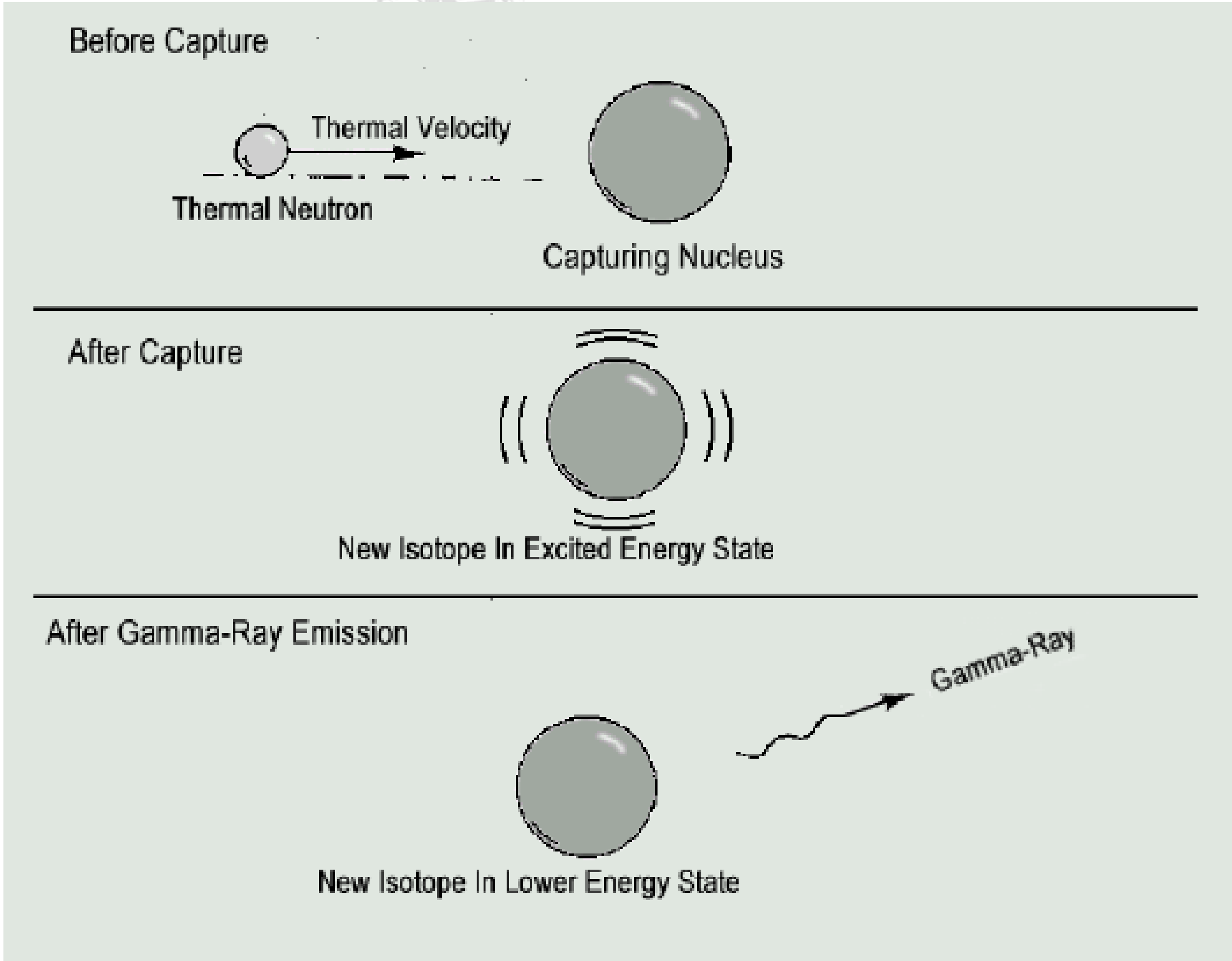
Thermal Neutron Dispersion

- **Thermal neutrons diffuse from volumes of higher concentration towards volumes of lower concentration**

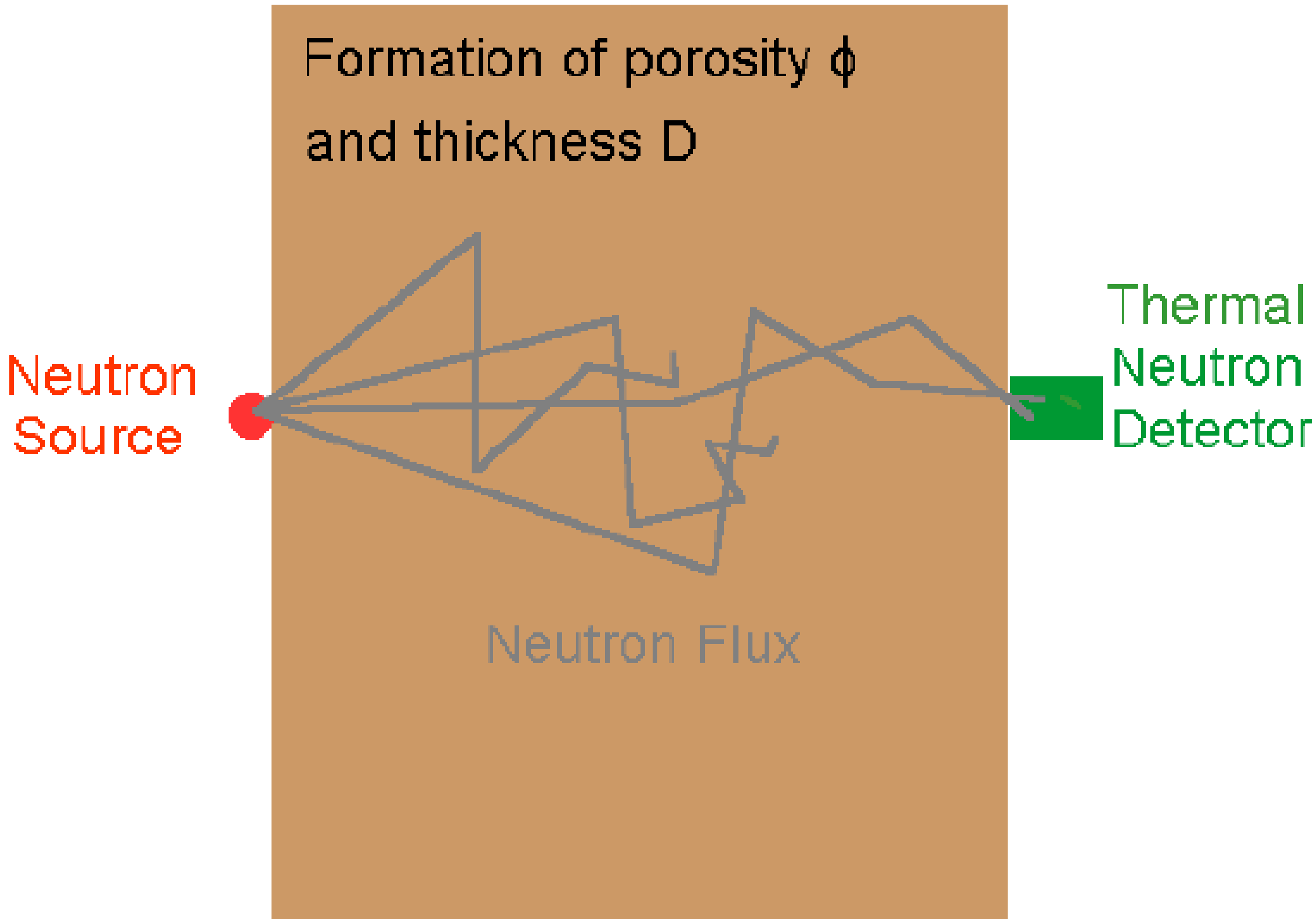


Thermal Neutron Capture

- **Thermal neutrons are captured by atomic nuclei which then emit gamma rays**
- **Chlorine usually plays the most important role in this process.**



A Simple Experiment

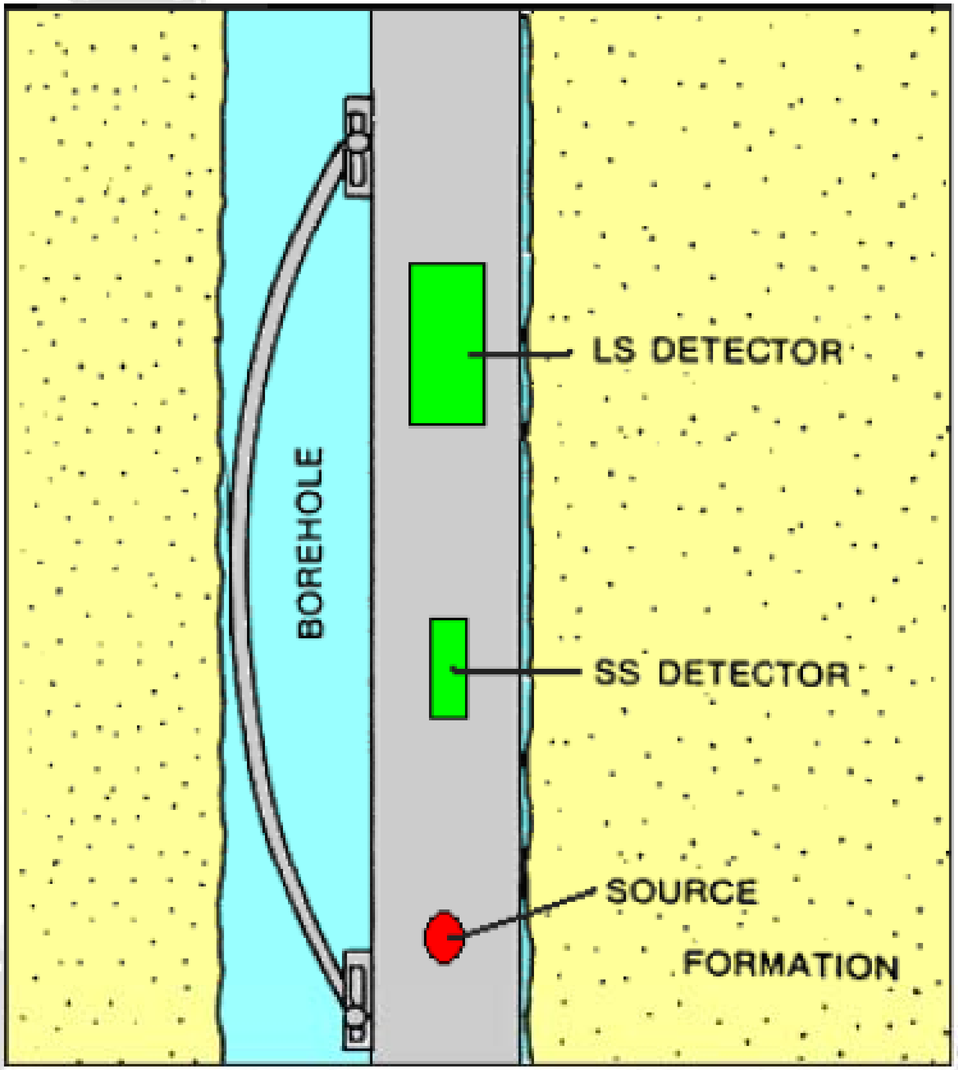


Compensated Neutron Log

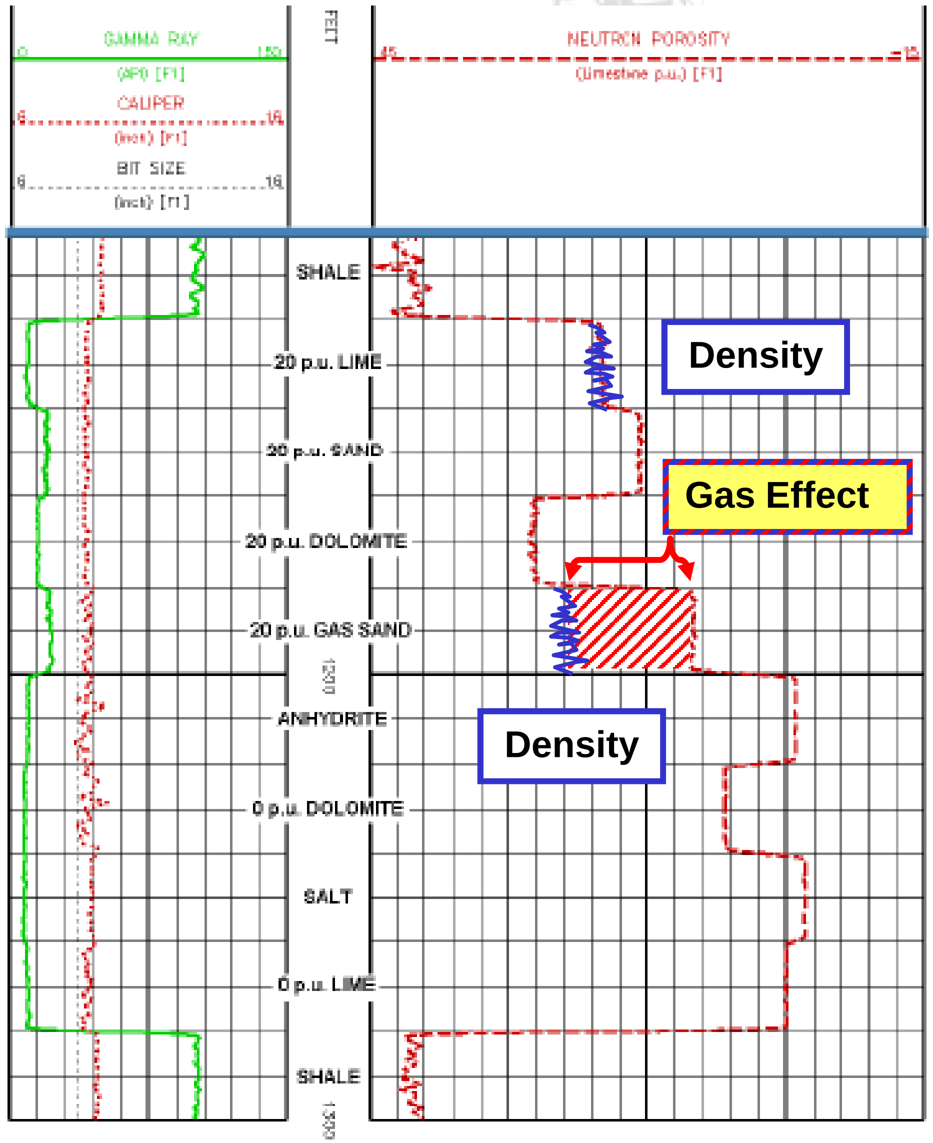
Typical instrument configuration:

He^3 detectors

Source: AmBe or Cf^{252}
Strength: 15 - 18 Ci or ~18 mCi
Output: 4.5 or 2.35 MeV Neutrons
Half-life: 432 years or 2.6 years
Rate: ~4 X 10^7 Neutrons/sec



Typical CN Log Responses



Spectral Gamma Ray – clay is deadly to a well

- The energies of the gamma rays are used to measure amounts of potassium, uranium and thorium in the formation
- Concentrations of these, plotted along with total gamma ray counts are used in the identification of clay type and for other reasons
  - Adjustment for total pore space available due to clogging by the clays (subtracts available porosity)
  - Affect of clay types on the design of stimulation and treatment practices for the well (Clay swelling)

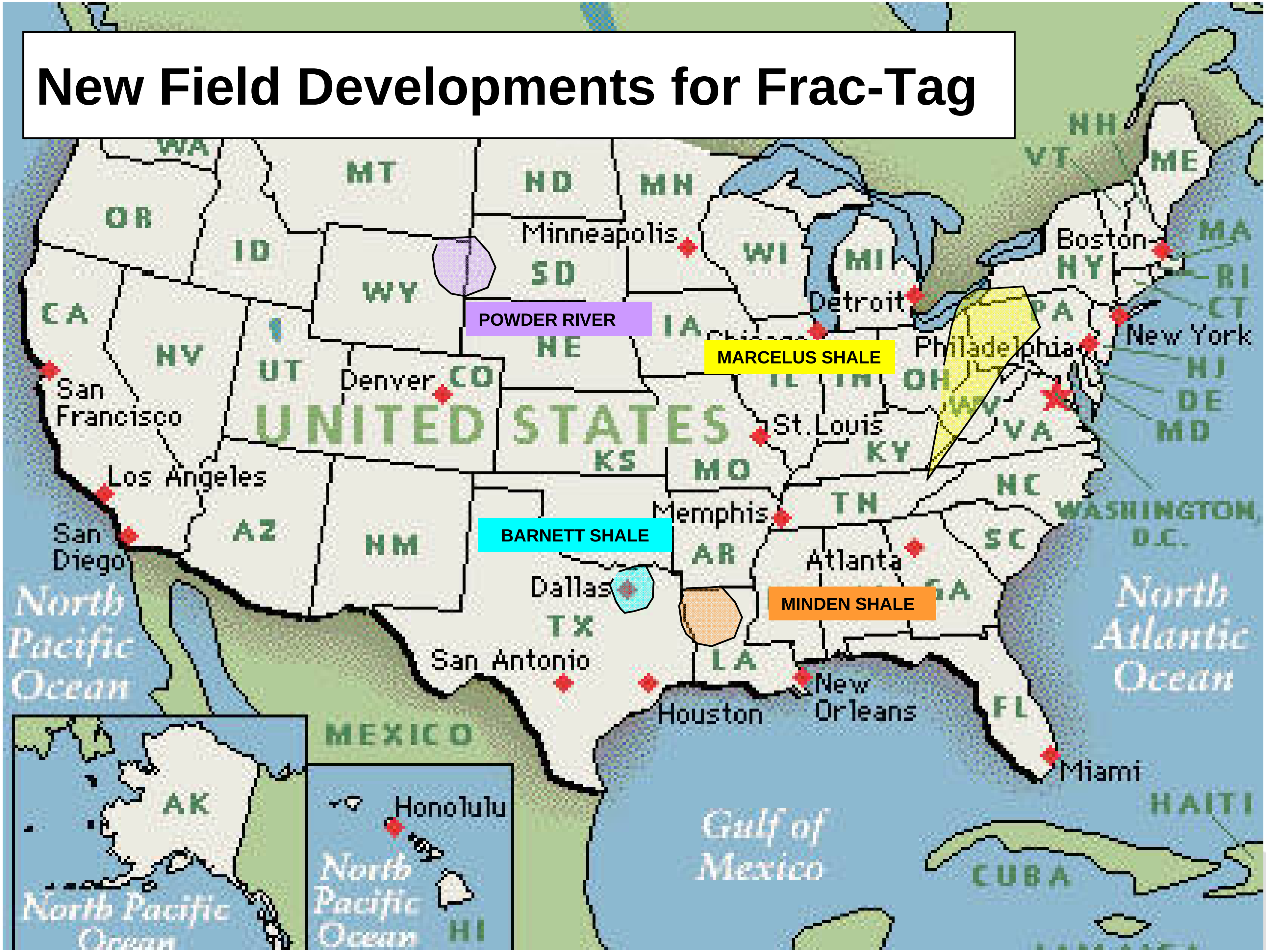
Radioactive Tracer & Production Logging – checking the health of the well.

- Short half-life radioactive tracers are injected into the well fluids under dynamic or static conditions to monitor flow of the fluids
- Dual detectors can calculate the direction and flow rates inside and outside of the casing or tubing
- Density-type production logs can detect changes of produced fluid density within the well-bore to determine contribution of fluids and gasses vs depth to optimize the production
- Pulsed-neutron logs are used for monitoring changing fluid levels behind pipe in the formation and giving indications of by-passed production

Other - Non- Logging Radioisotope Applications

- **Essential in the life of oil and gas wells**
  - **New Well Completions**
    - **Frac Tagging, Pips, ROP**
  - **Old Well Re-completions**
    - **Frac Tagging, ROP**
- **Improvement in efficiencies and safety**
  - **Stimulation**
  - **Production**
  - **Deliverability (Pipeline)**
    - **Industrial Radiography**
  - **Refining (Process Piping)**
    - **Industrial Radiography**

New Field Developments for Frac-Tag

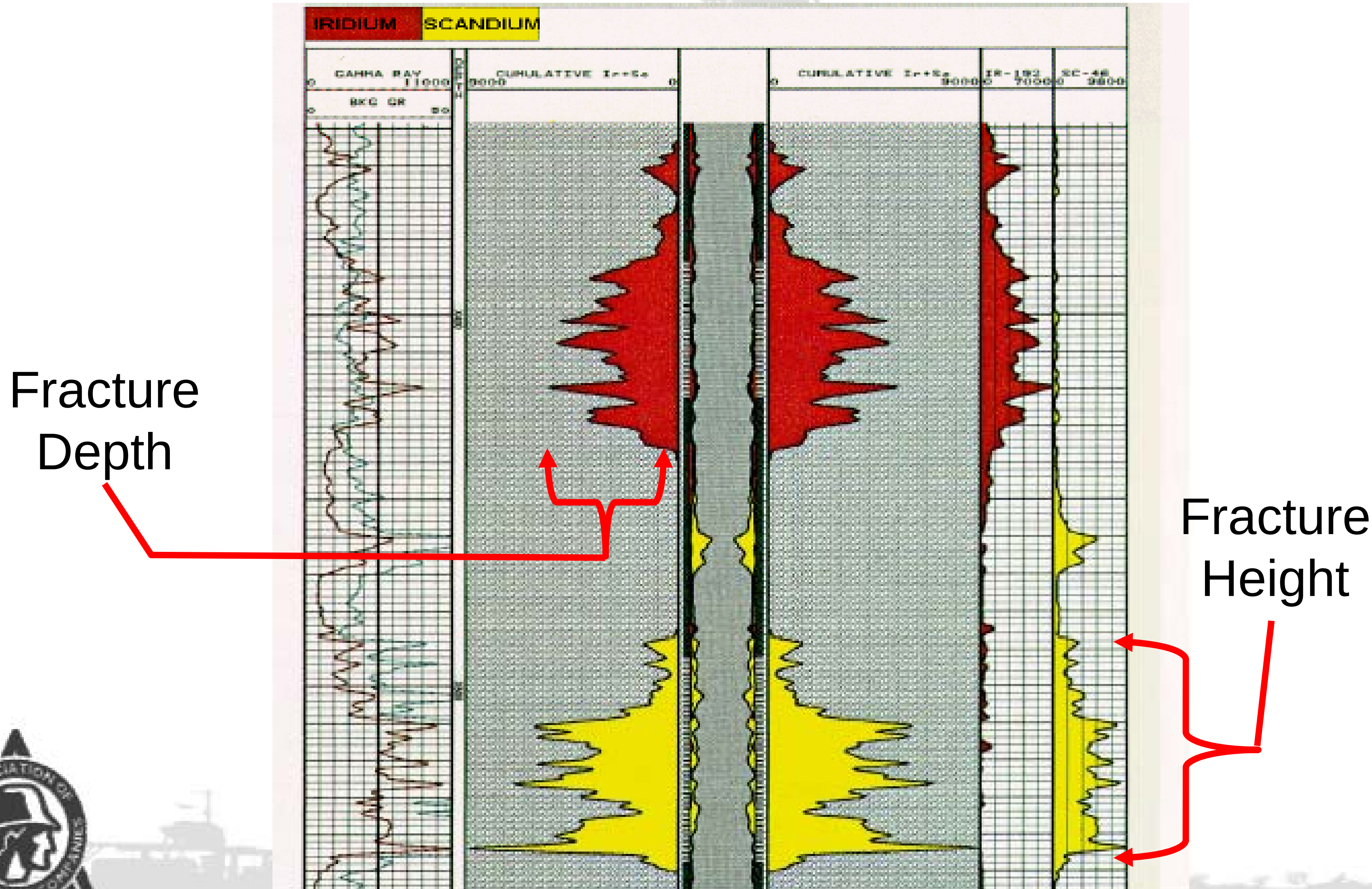


Frac-Tagging Operations

- **Radioisotopes introduced into the fluids that are used to force the rock formations to fracture by pump pressure and to remain open by proppant.**
- **Isotopes commonly used**
  - **Iridium-192 and 194 (40-100 mCi)**
  - **Scandium-46 (40-100 mCi)**
  - **Antimony -124 and 122 (40-100 mCi)**
- **Identifies fracture height, depth and efficiency**
  - **Spectral GR detector measures**
    - **Emergence of pumped-in isotopes back to the wellbore vs time for frac flow efficiencies**
    - **Shape of fracture envelope**
    - **Total vertical height of fracture**

AESC

Frac-Tagging Log



Other - Non- Logging Radioisotope Applications

- Industrial Radiography
- Radiological Positioning - pips
- Radiological Orientation – perforating (ROP)
- Storage Cavern Fluid Levels
- Density Gauges

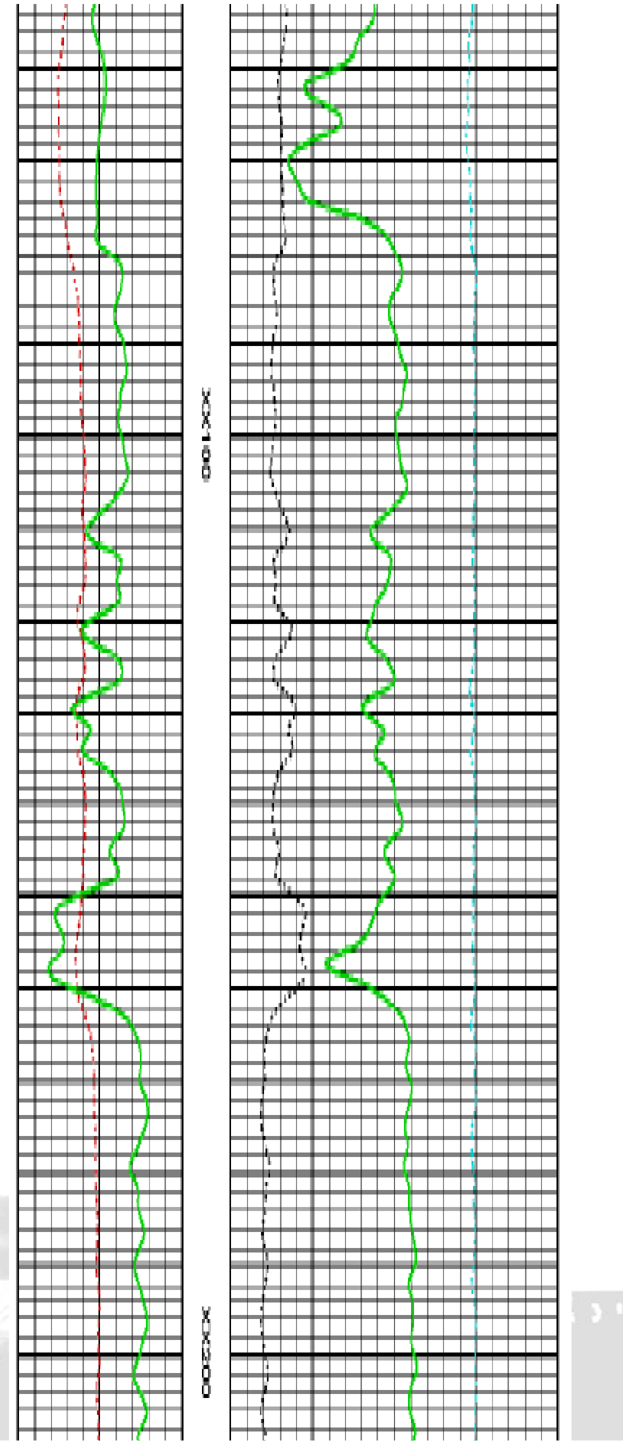
Tracer Isotopes and Half-lives

- Iridium-192 (Ir-192) 73.8 days
- Iridium-194 (Ir-194) 19.3 hours
- Scandium-46 (Sc-46) 83.81 days
- Antimony -124 (Sb-124) 60.2 days
- Antimony -122 (Sb-122) 2.7 days
- Sodium -24 (Na-24) 14.96 hours
- Iodine-131 (I-131) 8.1 days
- Silver-110m (Ag-110m) 249.8 days
- Bromine – 82 (Br-82) 1.5 days
- Cobalt-60 (Co-60) 5.3 years
- Gold-198 (Au-198) 2.7 days

Typical Source Summary

Service	Source Field	Calibrator/Verifier
Gamma Ray	none	2.5 µCi Ra-226
Spectral GR	none	2.5 µCi Ra-226
Tracer logging	tracer	2.5 µCi Ra-226
Spectral Density	2.5 Ci Cs-137	540 µCi Cs-137
		.8 µCi Cs-137 ECS
CN	15 - 18 Ci AmBe	400 mCi AmBe
	10 – 20 mCi Cf^{252}	
PNL (all modes)	pulsed D-T ~10^8 n/s	2.5 µCi Ra-226

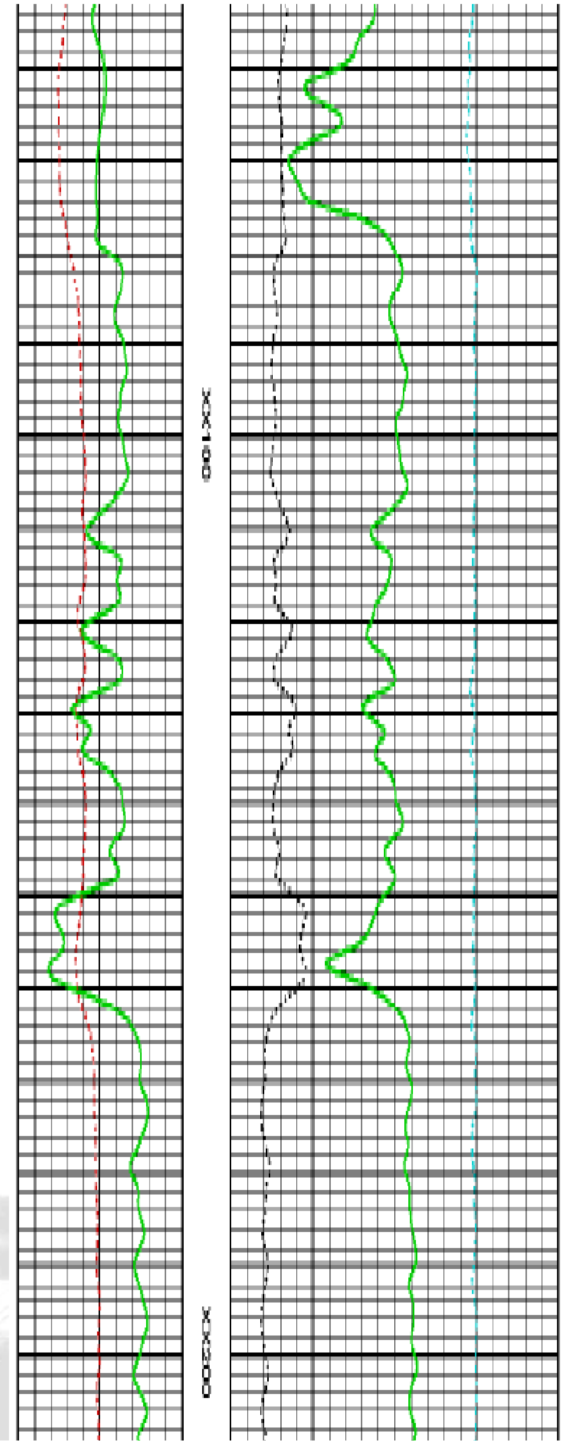
Sources used by other companies will be slightly different



ASSOCIATION OF ENERGY SERVICE COMPANIES

AESC

QUESTIONS?



ASSOCIATION OF ENERGY SERVICE COMPANIES
AESC