Carbon-14 in LS

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Introduction

- Carbon-14 goes through radioactive **beta decay**:

$$^{14}C \rightarrow ^{14}N + e^{-} + \bar{\nu}_e \quad (Q_\beta = 156 \text{ keV})$$

  - decay constant = 3.8×10^{-12}/s
  - decay rate in typical LS < 0.2/s/ton @ $^{14}C/^{12}C = 10^{-18}$

- R (= $^{14}C/^{12}C$) measurements

Liquid Scintillator	$^{14}C/^{12}C$ ($\times10^{-18}$)	Experiment
PC + PPO	1.94 ± 0.09	Borexino CFT
PXE + p-Tp	9.1 ± 0.4	Borexino CFT
PC-Dodocane + PPO	3.84 ± 0.94	KamLAND
LAB + PPO	24.8 ± 8.2	Dedicated setup

Source of ^{14}C in Petroleum

- **Nuclear reactions**

Reaction	σ(millibarn)	Comment
$^{17}O(n,\alpha)\ ^{14}C$	235	-
$^{14}N(n,p)\ ^{14}C$	1830	-
$^{13}C(n,\gamma)\ ^{14}C$	1.4	-
$^{11}B(\alpha,n)\ ^{14}C$	20-200	2-5 MeV energy
$^{226}Ra \rightarrow ^{14}C$	-	Tripartition

- $^{14}N(n,p)^{14}C$ reaction is the main source in oil fields.
  - Oil fields are found throughout the world in a wide variety of geological formations, over a range of depths from near the surface to 10000 meters.
  - Petroleum originates from decayed biomass, it is supposed to contain a lot of nitrogen. (Nitrogen content of oil averages 0.1 ~ 2%.)
  - Neutron comes from ^{238}U and ^{232}Th -> (α,n)
  - **R is predicted range of 10^{-16} ~ 10^{-20}**.

More on R

$$R \propto \frac{UMN}{B} = nN$$

- U: concentration of ^{238}U in the rock
- M: concentration of the various nuclei which ultimately generate the neutrons
- B: concentration of neutron absorber
- N: concentration of Nitrogen

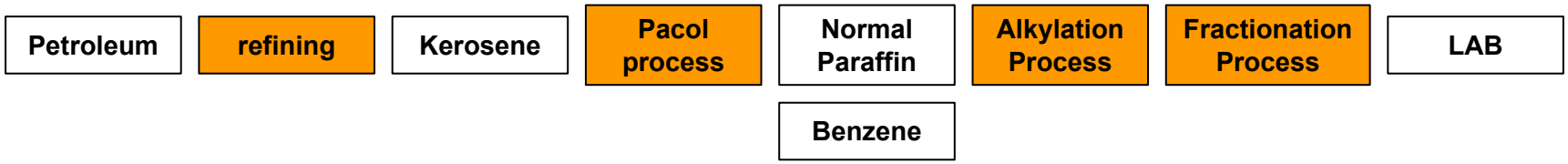
Type of rock	U(ppm) Refs.[4,8,9]	Th(ppm) Refs.[4,8,9]	B(ppm) Ref.[10]	n (n/grams/year) Ref.[4]
Sandstone	0.45 (0.2-0.6)	1.7 (0.7-2.0)	30 (5-70)	1.
Limestone	2.2 (0.1-9.0)	1.7 (0.1-7.0)	20 (2-95)	1.
Shale	3.5	11	130 (25-800)	1.

Is it possible to seek an oil field with a low concentration of Nitrogen and Uranium to reduce R?

Contamination

- Natural Carbon during solvent production
  - assume petroleum has R = 10^{-20}
  - R of ^{nat}C = 10^{-12}
  - over 1 mg contamination of ^{nat}C in producing 1 ton of solvent can make serious situation.

ex) process of LAB production



- Fluor
  - assume solvent has R = 10^{-20} and fluor has 10^{-15}
  - mass fraction of fluor in LS (~ 1/1000) leads to 10^{-18} of LS
  - **R of fluor should be less than 10^{-17}**
  - **need to be check**
- Exposure of LS to CO_2

Pursuit R = 10^{-20}

- It is very difficult to achieve !
  - An isotopic ratio for $^{14}C/^{12}C$ in the petroleum is expected to ~5×10^{-21}. (no experiment)
  - Practically, to control contaminations is critical.
  - check fluor contamination
  - nitrogen purging to remove CO_2

- Using direct products from petroleum as base solvent
  - Kerosene (so called **"White spirit"** liquid scintillator) or Normal Paraffin
  - less contamination during production process
  - but we need to add aromatic solvent (ex, PC) to increase light yield.