Aspects of how Tracers Compounds can Contribute to Optimize EOR/IOR Processes

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FORCE seminar
MEOR – from theory to field implementation
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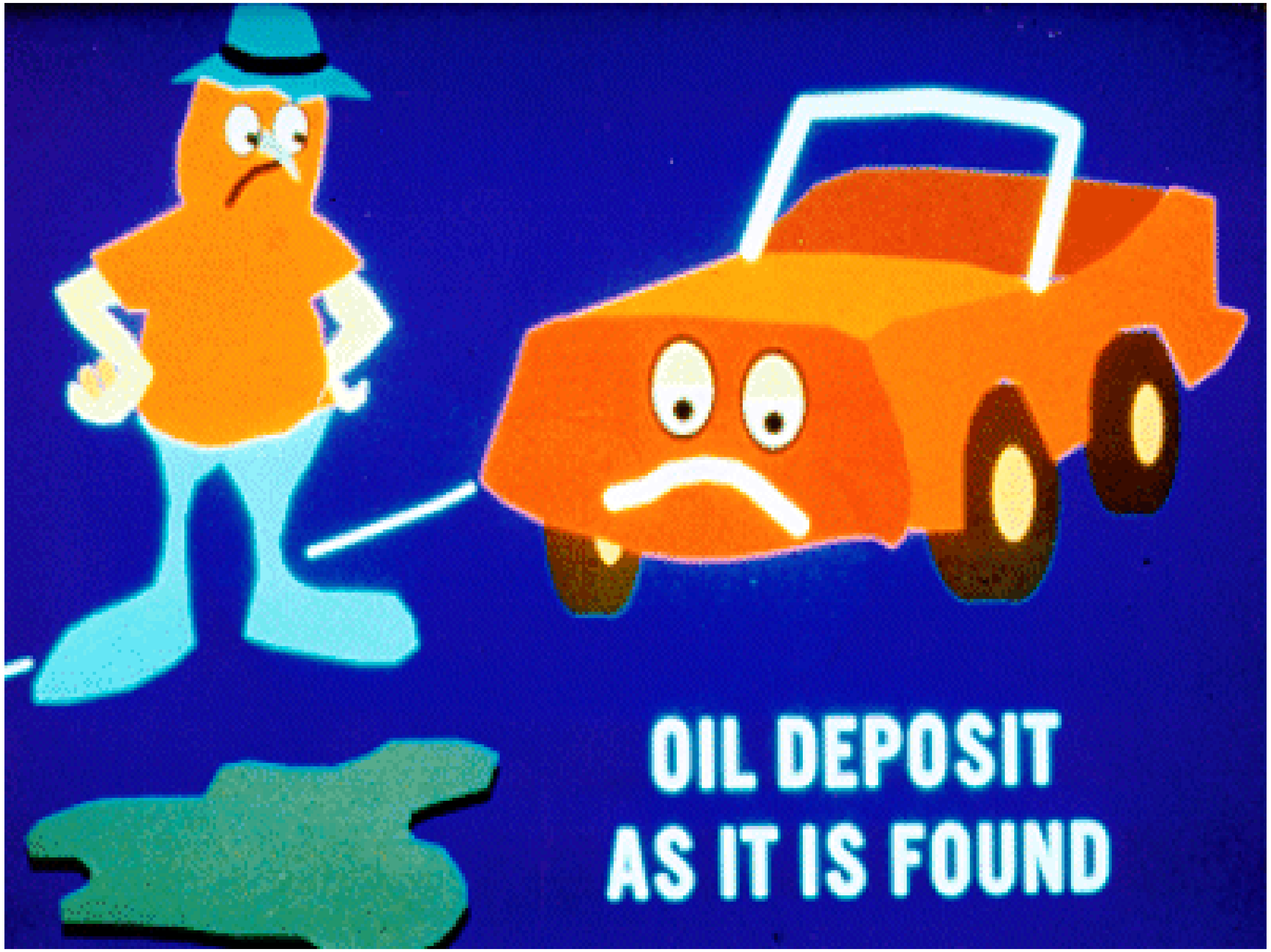
Outline:

- General on EOR/IOR
- Norwegian IOR Centre
- Tracer technology
- PITT (interwell SOR measurem.)
- SWCTT (near-well SOR measurem.)
- New developments

Traditional oil recovery steps

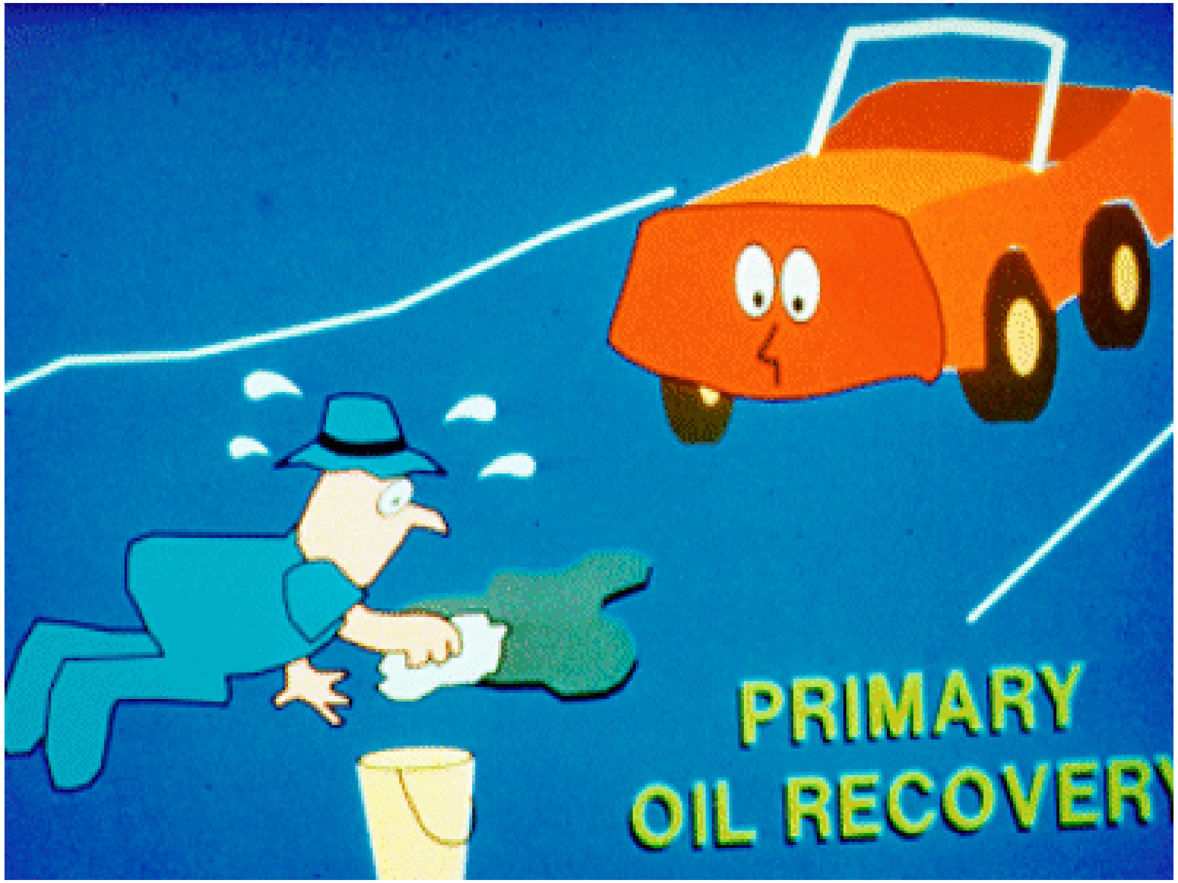
Given an oil deposit….

What to do about it?



Primary oil recovery

A method of oil recovery whereby the oil flows from the well by its own pressure or is pumped out. This method [recovers at best about 30%](#) of the oil in the reservoir.



A “dipper collects heavy oil

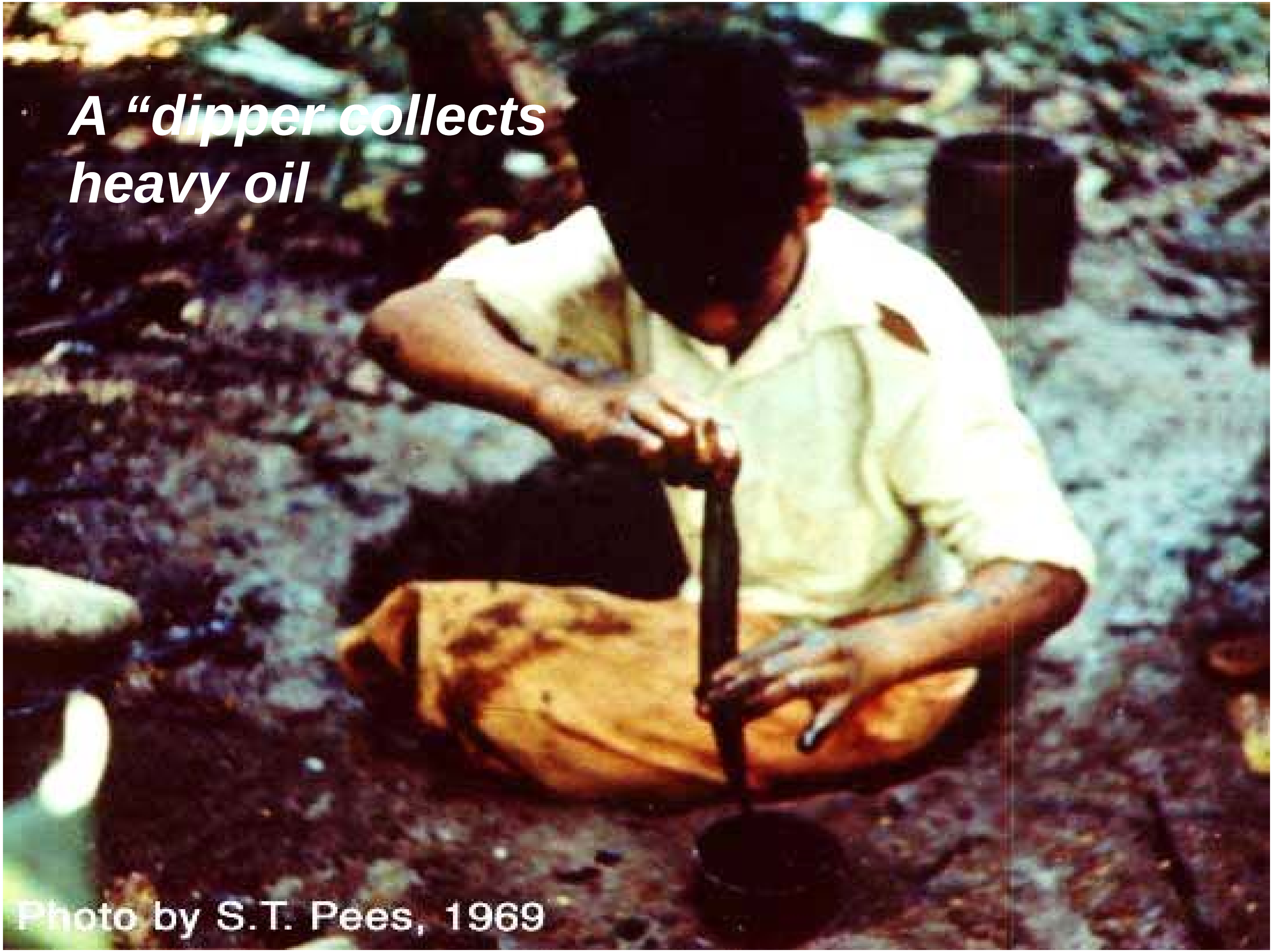


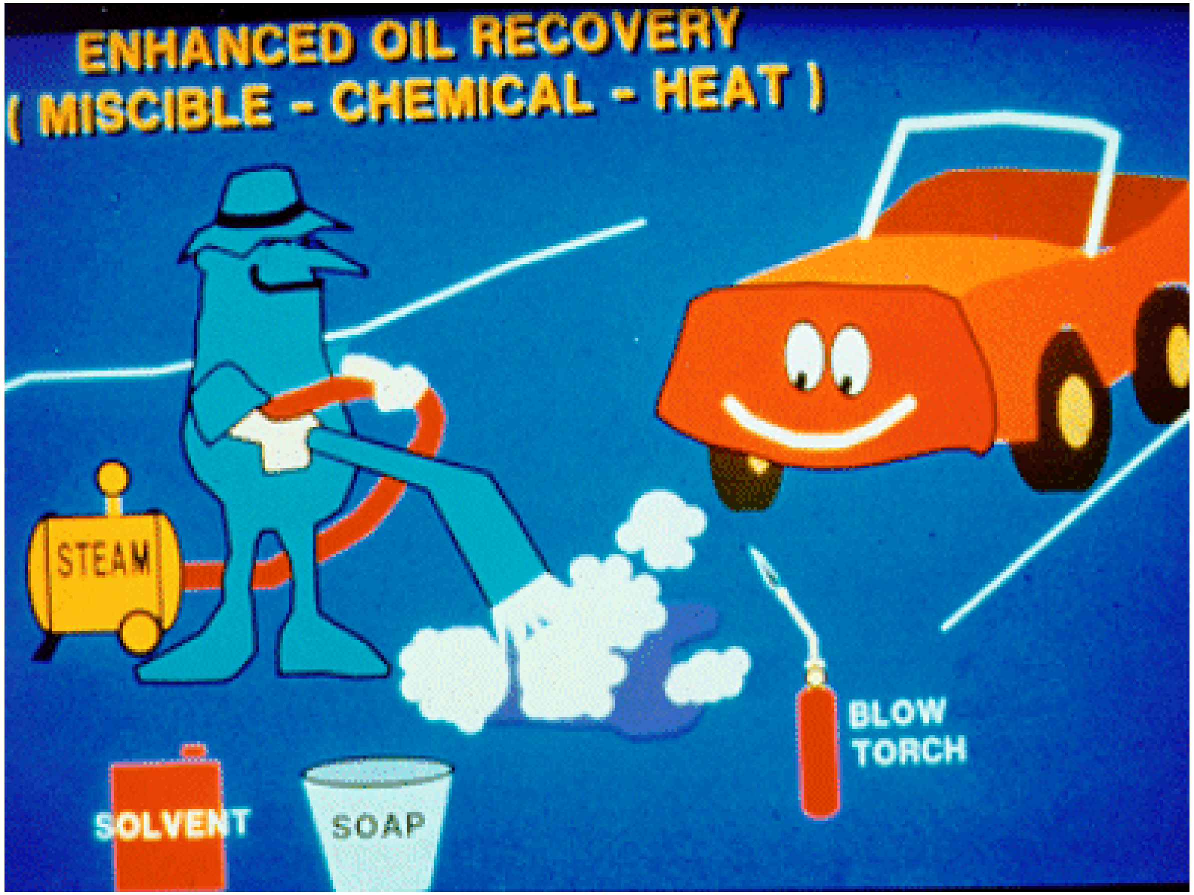
Photo by S.T. Pees, 1969

Secondary oil recovery

Method of oil recovery whereby the well is flooded with high-pressure water or gas, such as methane, to push the oil out. Recovers additionally about 20-30% of the oil in the reservoir.

Tertiary oil recovery

Method of oil recovery in which the oil is heated by various methods, or adding a polymer or detergent to scrub it out. Typically recovers only an additional 10% of the oil in the well after primary and secondary recovery.



We called this tertiary recovery level for

Enhanced Oil Recovery:

EOR

The concept of Improved Oil Recovery, IOR, was introduced including EOR but also a number of other topics and aspects like:

- *Improved reservoir description*
- *New well strategy and drilling technology*
- *Smart well completion methods*
- *Improved understanding of flow assurance*
- *Economy, i.e. sound economic processes*
- *Environmental considerations*
- *Even Sosial and sociological aspects etc.*

Modern strategy is to consider EOR/IOR from day 1 in the field development

The National Norwegian IOR Centre

The aim:

- Contribute to maximizing oil recovery on the Norwegian Continental Shelf
  - Research and development for field implementation
  - Environmentally friendly technologies

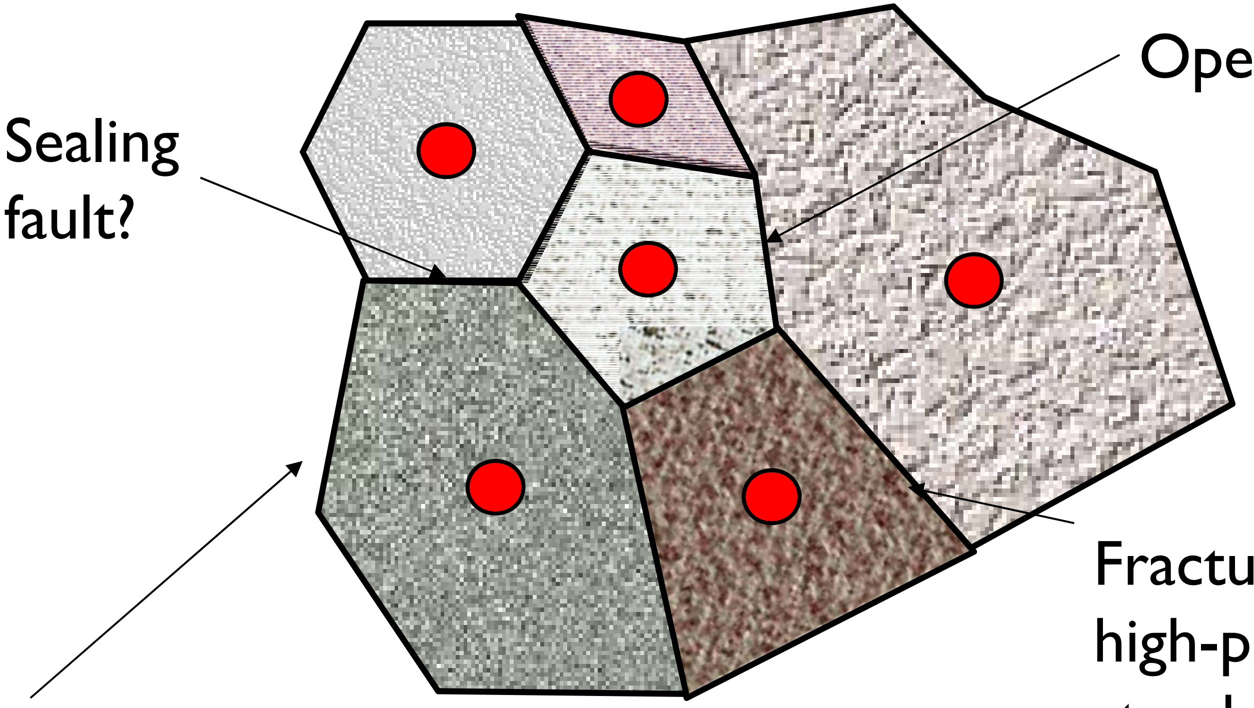
User partners (so far):

DETNORSKE bp eni Statoil MAERSK wintershall Wir fördern Zukunft. GDF SUEZ BY PEOPLE FOR PEOPLE

Lundin Petroleum ConocoPhillips DONG energy Schlumberger HALLIBURTON Forskningsrådet

Tracers for reservoir characterization

Reservoir compartment studies



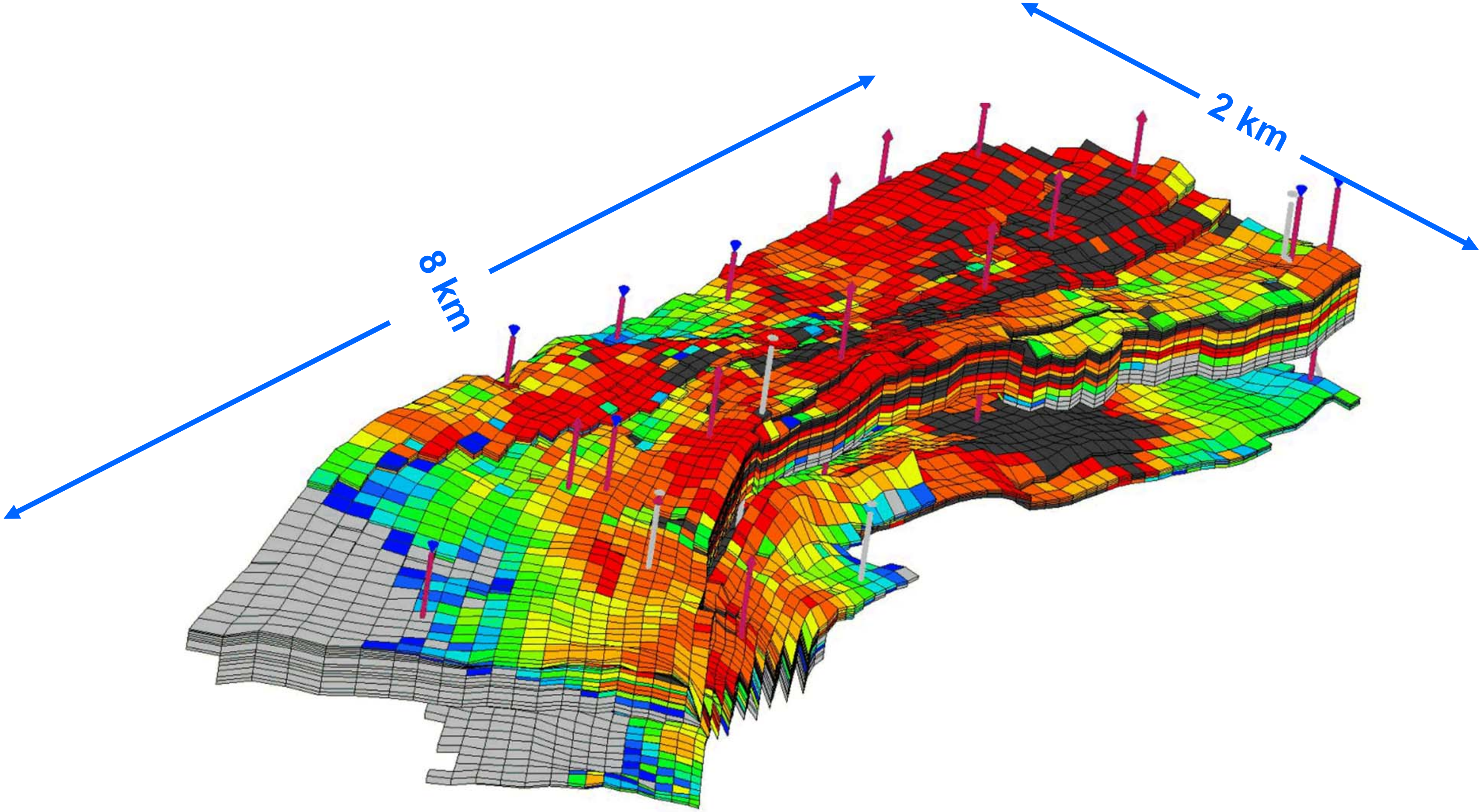
Sealing fault?

Open fault?

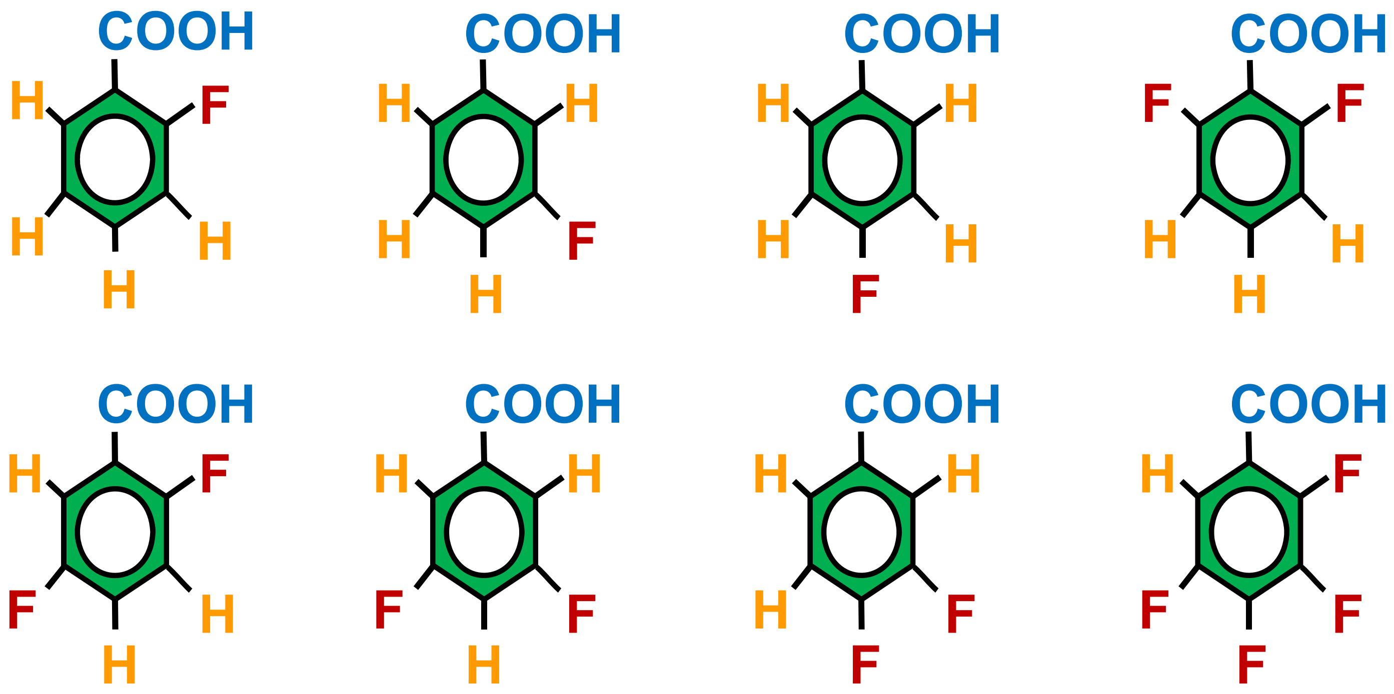
Fracture/ high-permeability streak?

Fluid flow directions?

Water expelling oil –should be traced

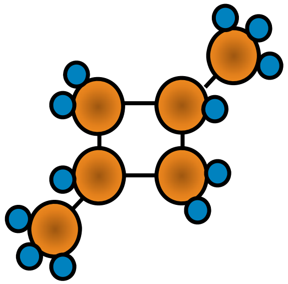


Non-radioactive polyfluorinated interwell water tracers

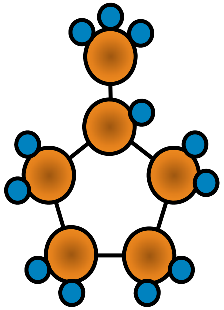


Non-radioactive gas tracers

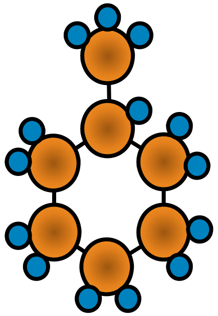
Perfluorinated cyclic hydro-carbons with coordinated light hydrocarbon (methyl) groups are excellent gas tracers



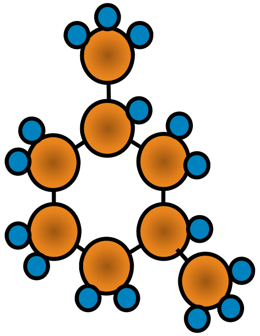
PDCB



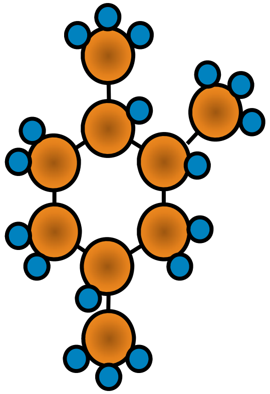
PMCP



PMCH



1,3-PDMCH

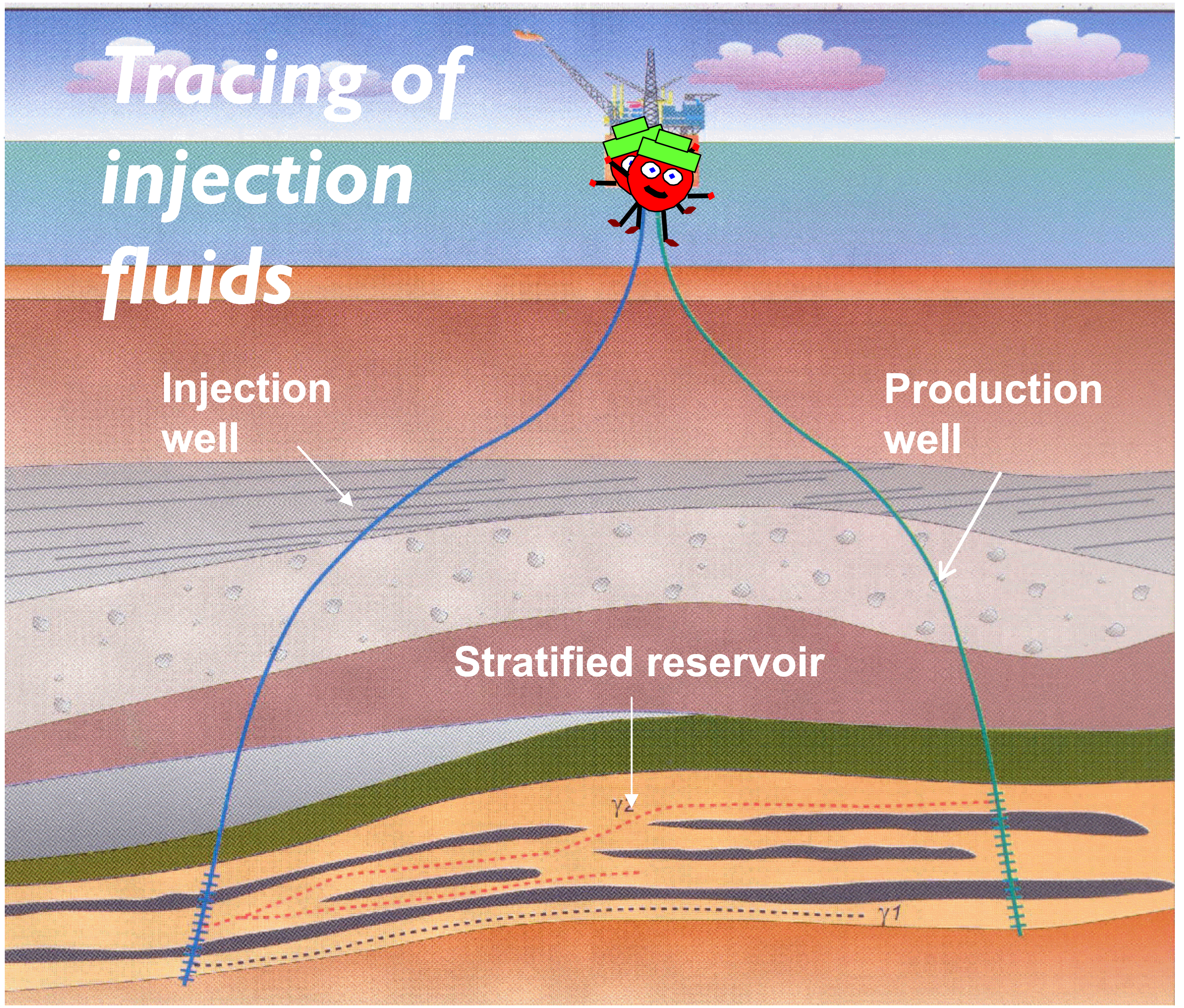


1,2,4-PTMCH

● CARBON

● FLUORINE

Tracing of injection fluids



PITT

PITT principle

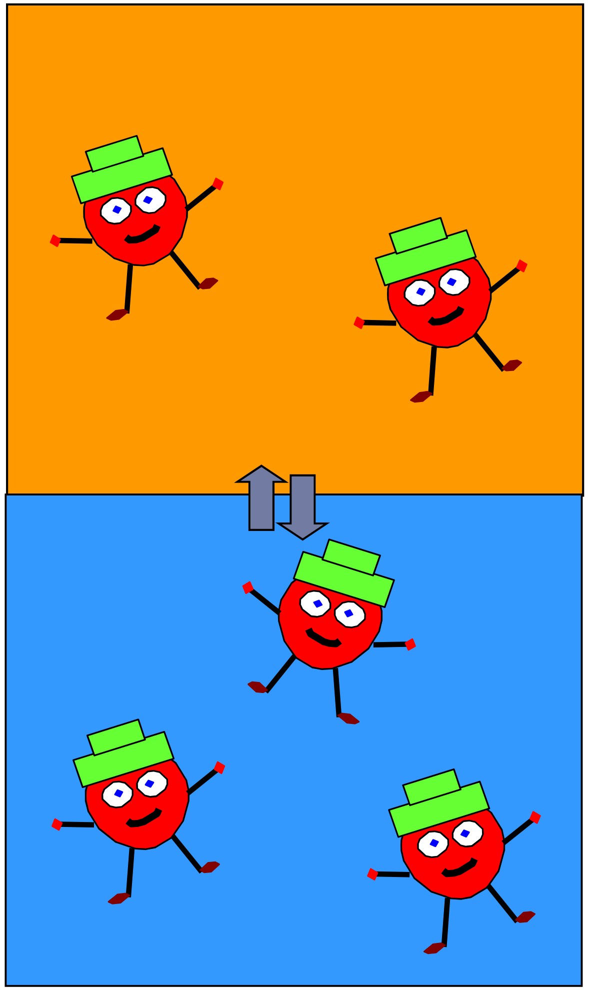
- **Exploits the delay of water/oil or gas/oil partitioning tracers compared to nonpartitioning (passive) tracers between injection well and production well**
- **Works by injecting partitioning and passive tracers simultaneously**
- **Water or gas contactable average residual oil saturation in swept volume can be estimated by:**

$$S_o = (T_p - T_{np})/[T_p + T_{np}(K - 1)]$$

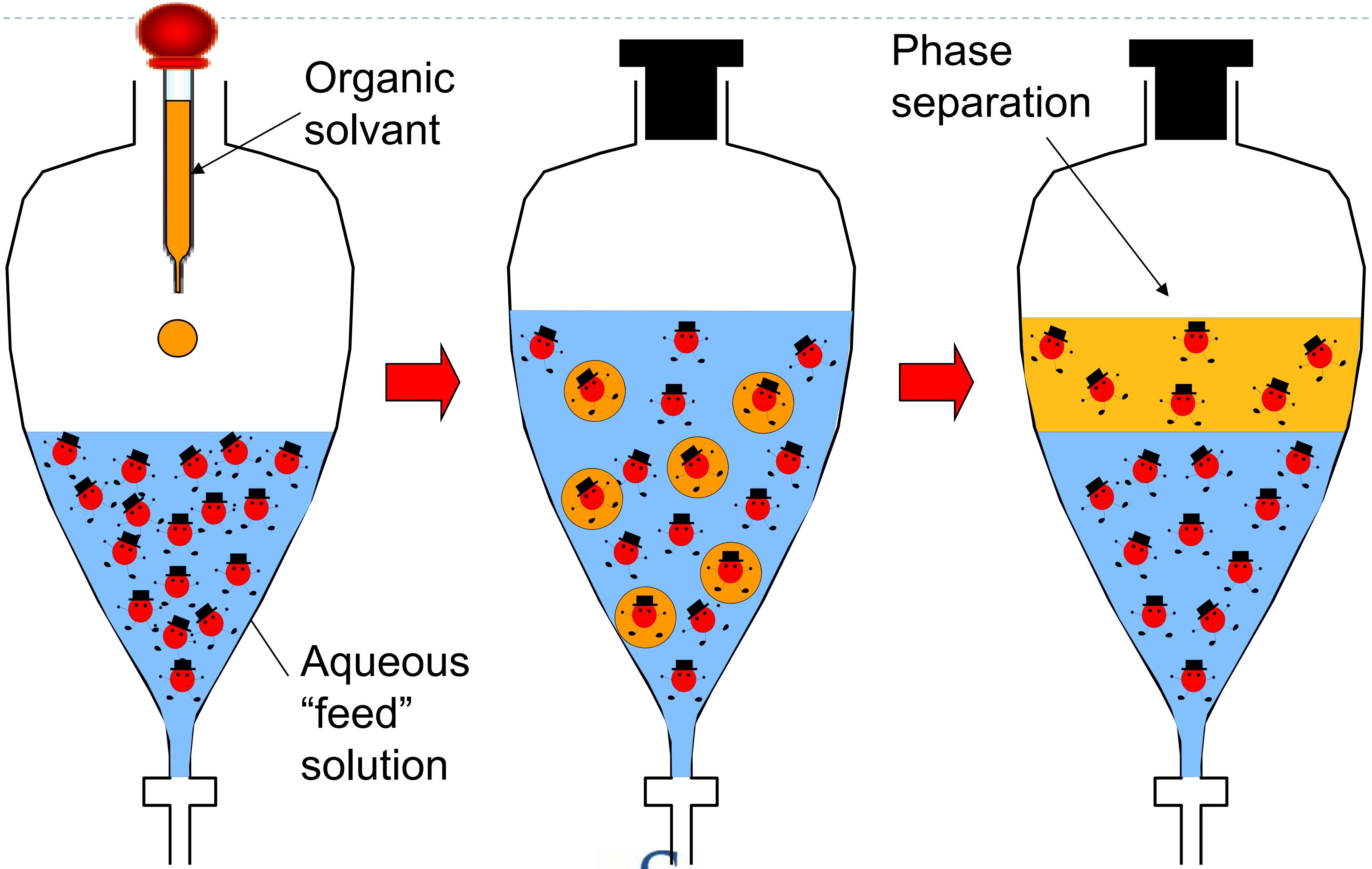
K-value (partition coefficient)

- Non-partitioning tracer exist only in water
- Partitioning tracer distributes in water and oil
- Water moves, oil is (close to) stagnant in EOR cases

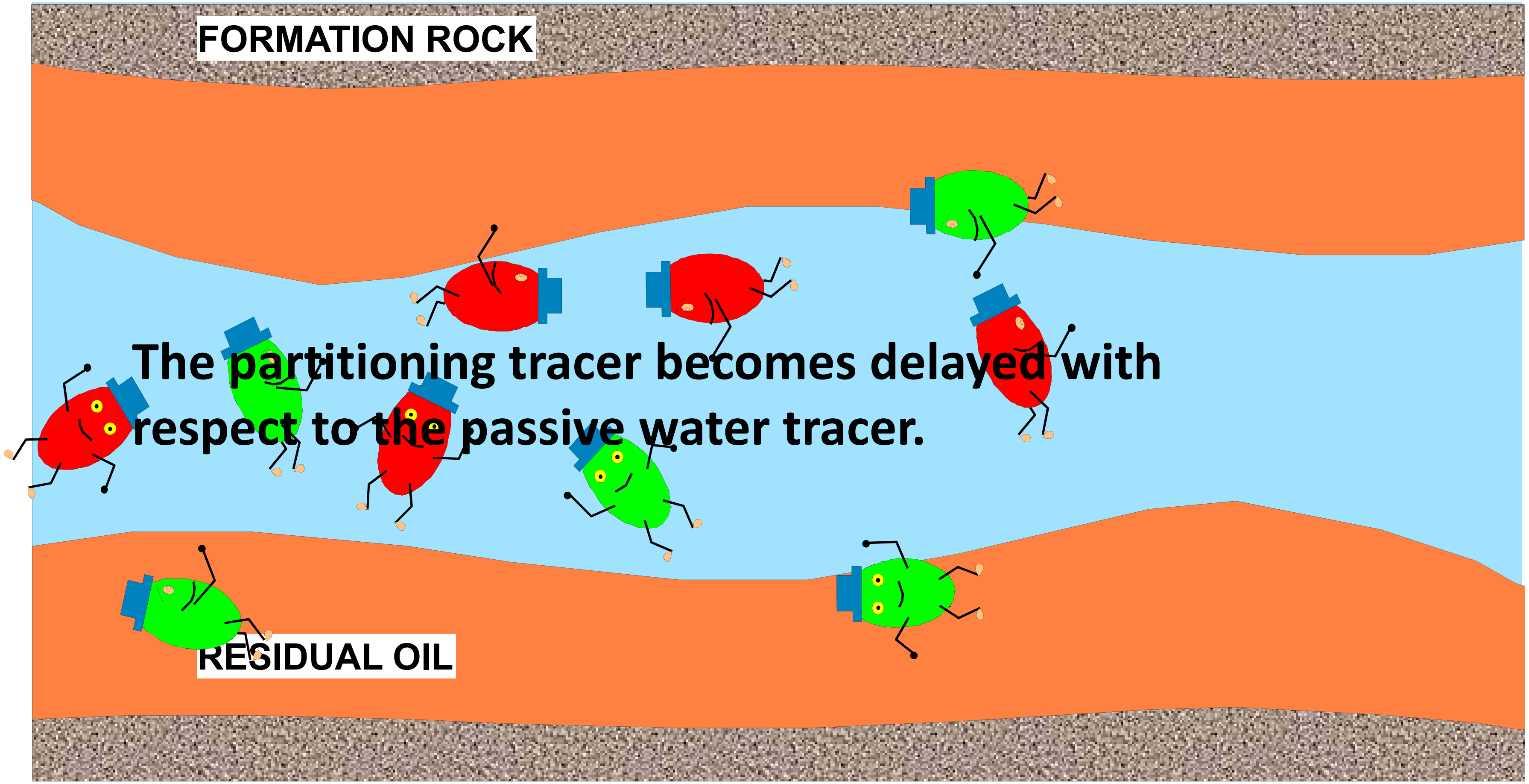
$$K = (C_{Tr})_o/(C_{Tr})_w$$



Phase partitioning

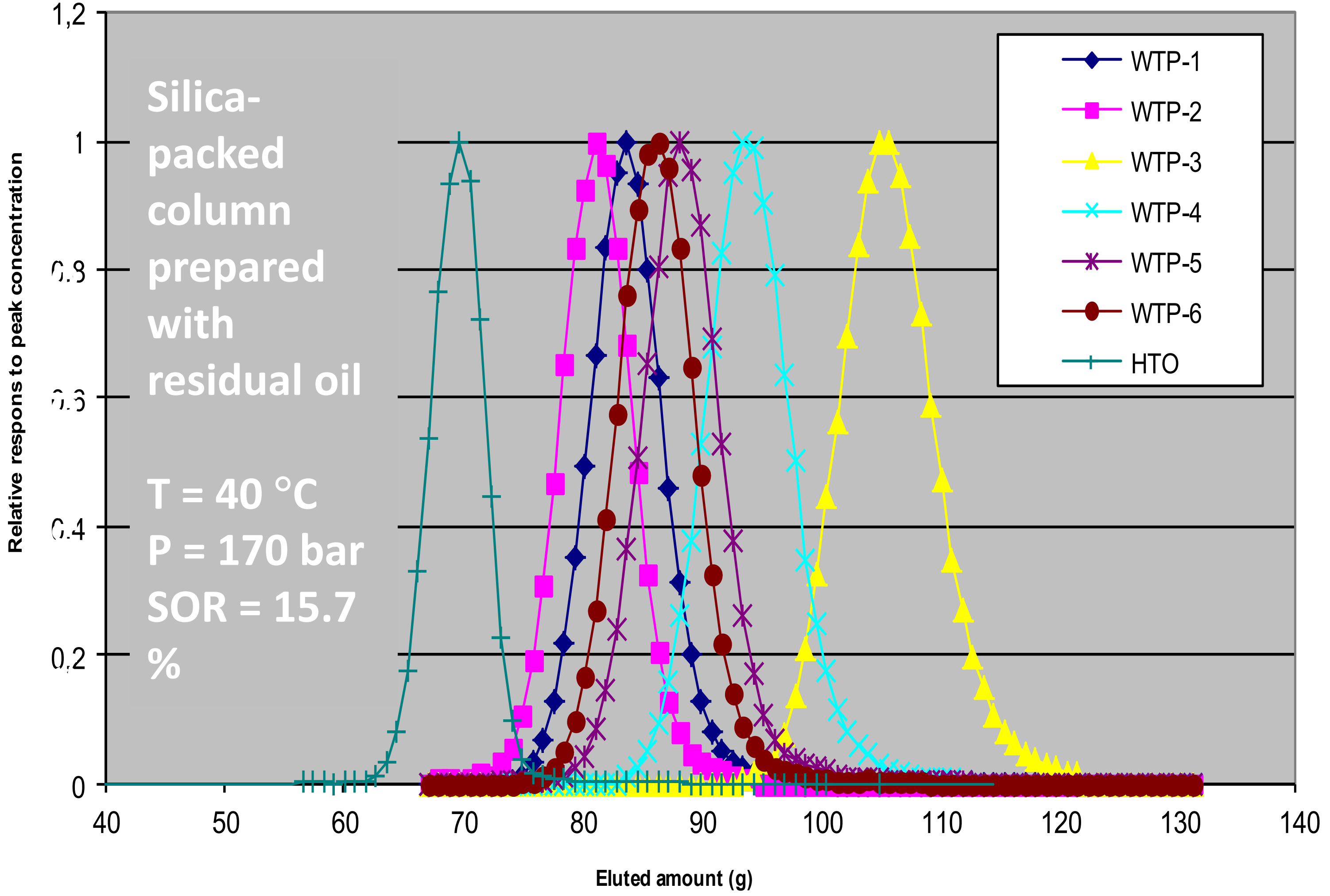


Passive and partitioning tracer flow in a flooding pore of formation rock



The partitioning tracer becomes delayed with respect to the passive water tracer.

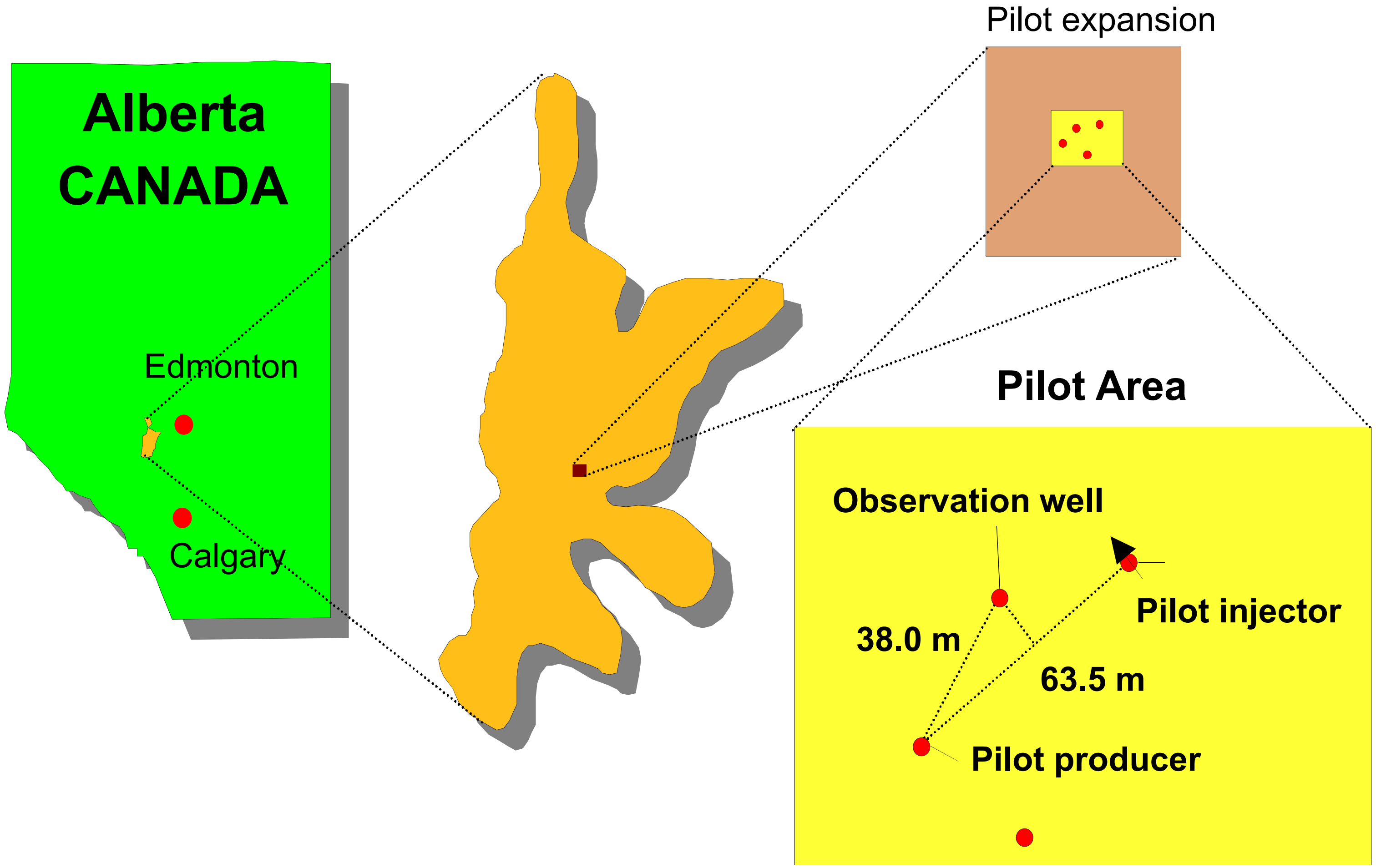
Partitioning tracer – Lab Experiments



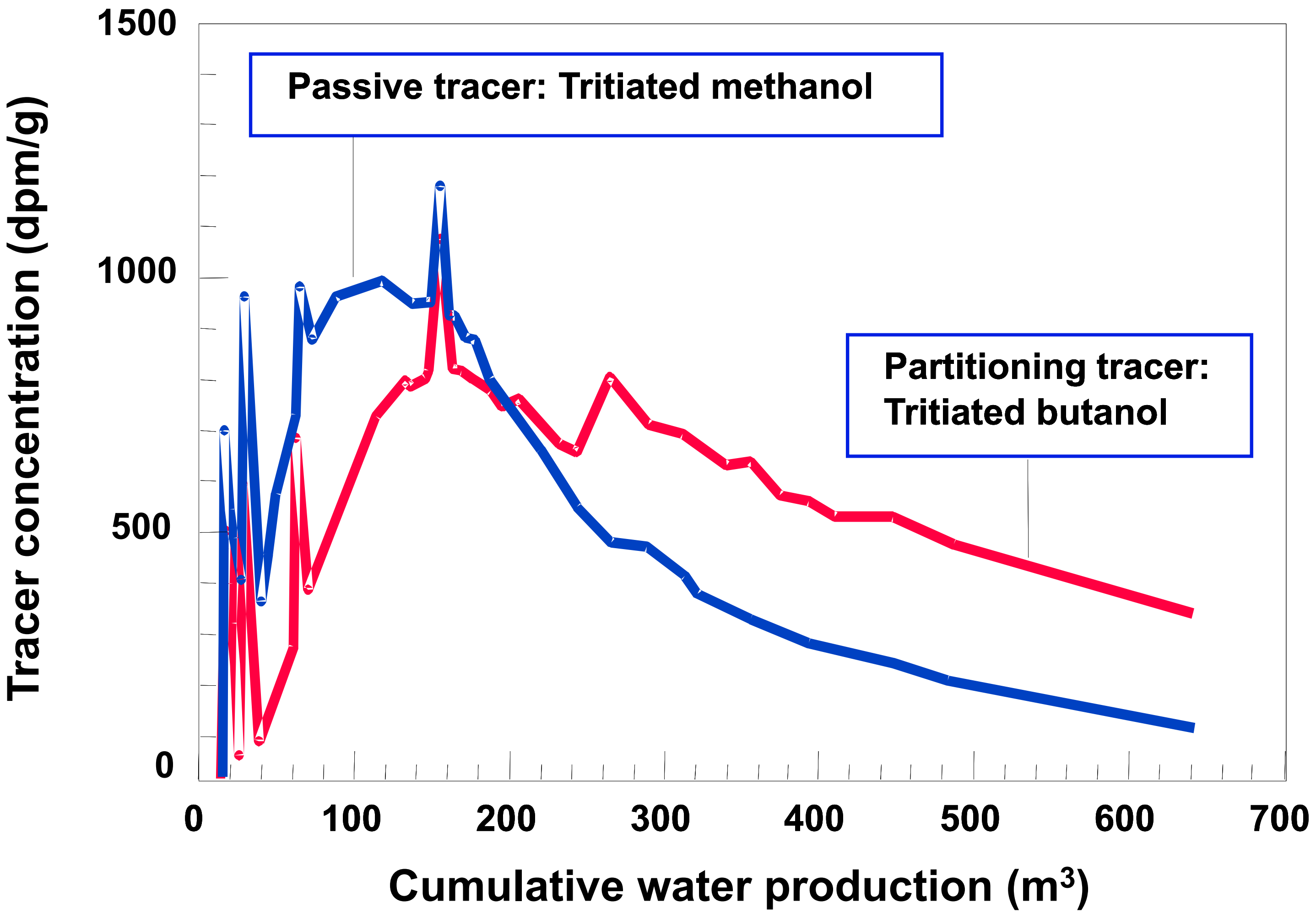
Silica-packed column prepared with residual oil

T = 40 °C
P = 170 bar
SOR = 15.7 %

First PITT: Leduc D-2A Pool Outline



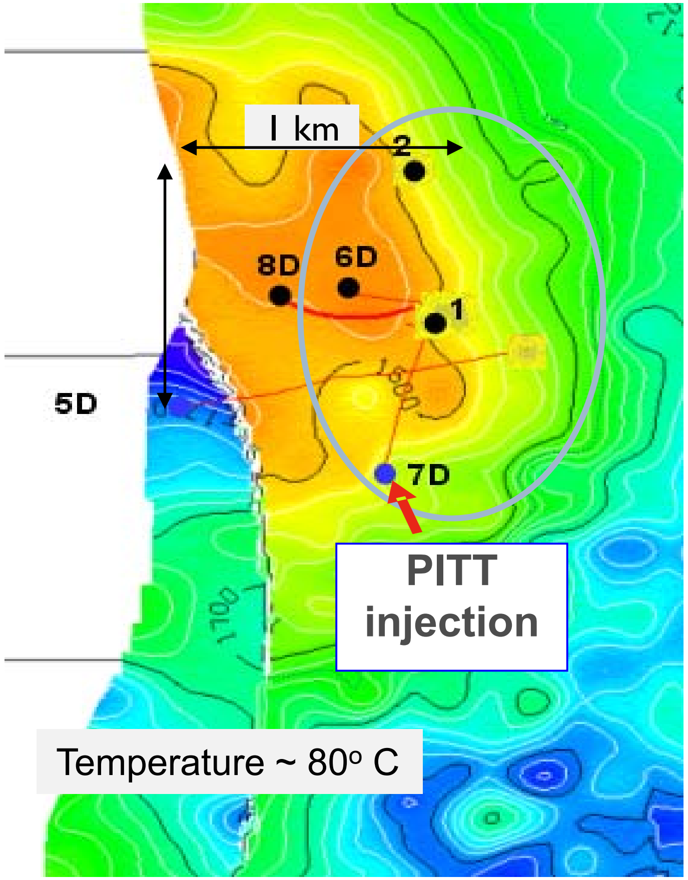
First PITT: Tracer production curves



PITT SOR results

Method	Results SOR %
IWTT	35 ± 1
SWTT 1 (spm)	40 ± 3
SWTT 2 (dpm)	35 ± 3
SWTT 3 (mbm)	35 ± 3
Sponge coring	33

PITT operation in the Lagrave field



PITT injection

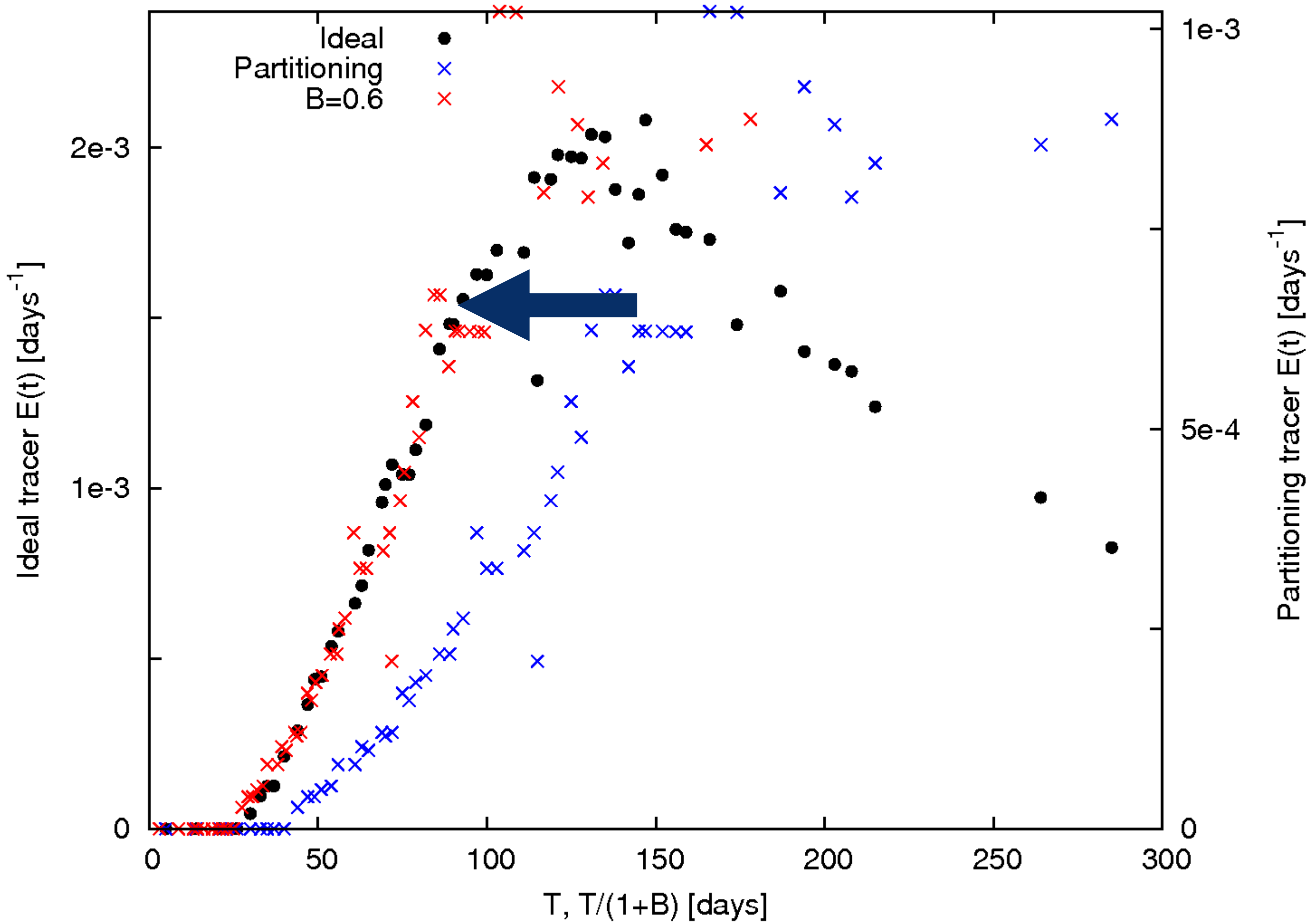
Temperature ~ 80° C

Tracer injection in LAV-7
16.02.2011

Tracer	Type	K	Amount [kg]
T1	Partitioning	2.1	5
T2	Partitioning	1.5	5
T3	Partitioning	1.5	5
T4	Partitioning	2.9	5
T7	Partitioning	2.4	5
T8	Partitioning	1.9	5
2-FBA	Passive	0	5

Ref.: SPE 164059

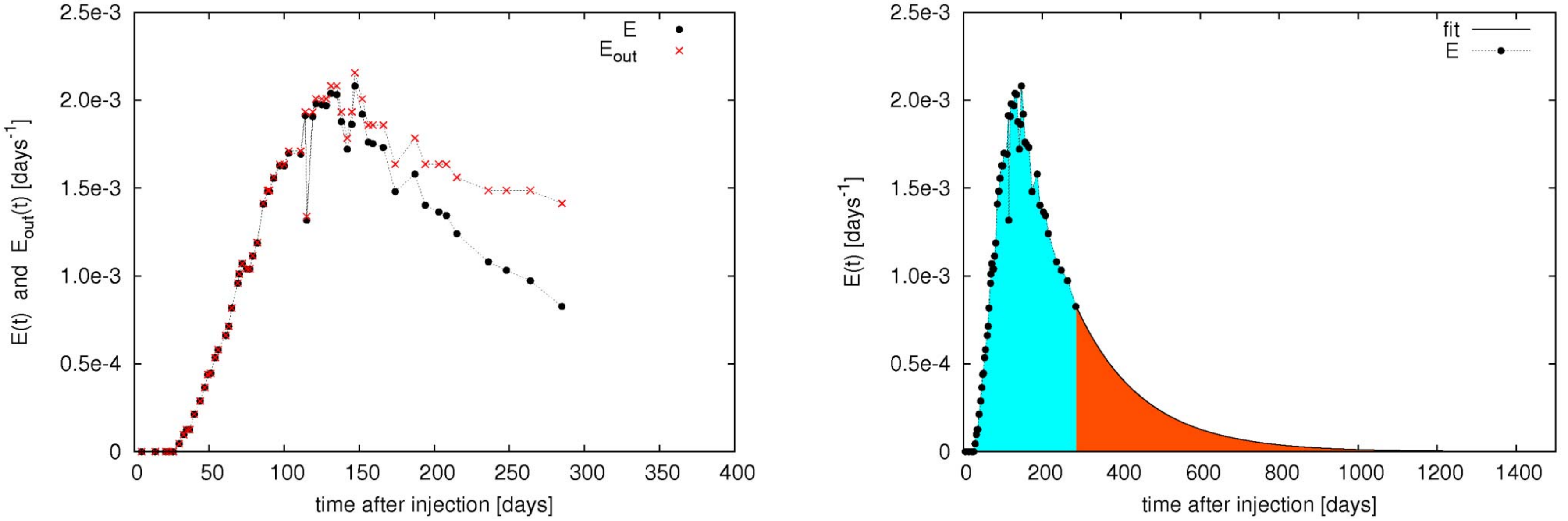
Estimation of S_o by scaling x-axis



Scaling x-axis of the partitioning tracer : $x' = x / (1+\beta)$

RTD analysis of PITTs

Must first correct for re-injection & extrapolate to infinity



LAV-1 results

Tracer	β	K	$\overline{S_o}$ [%]	$\overline{S_o}$ [%]
IFE-WTP8	0.6	1.9	24	Average saturation measured on cores: 25 %
IFE-WTP7	0.75	2.4	24	
IFE-WTP3	0.50	1.5	25	
IFE-WTP2	0.50	1.5	25	
IFE-WTP1	0.70	2.1	25	
IFE-WTP4	0.80	2.9	22	

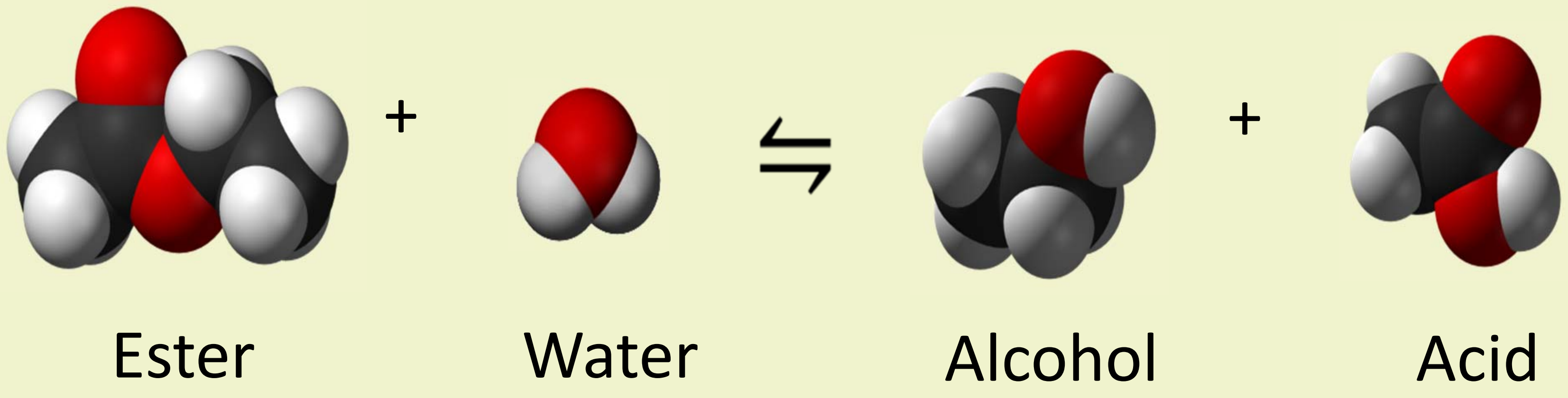
Results are consistent

SWCTT

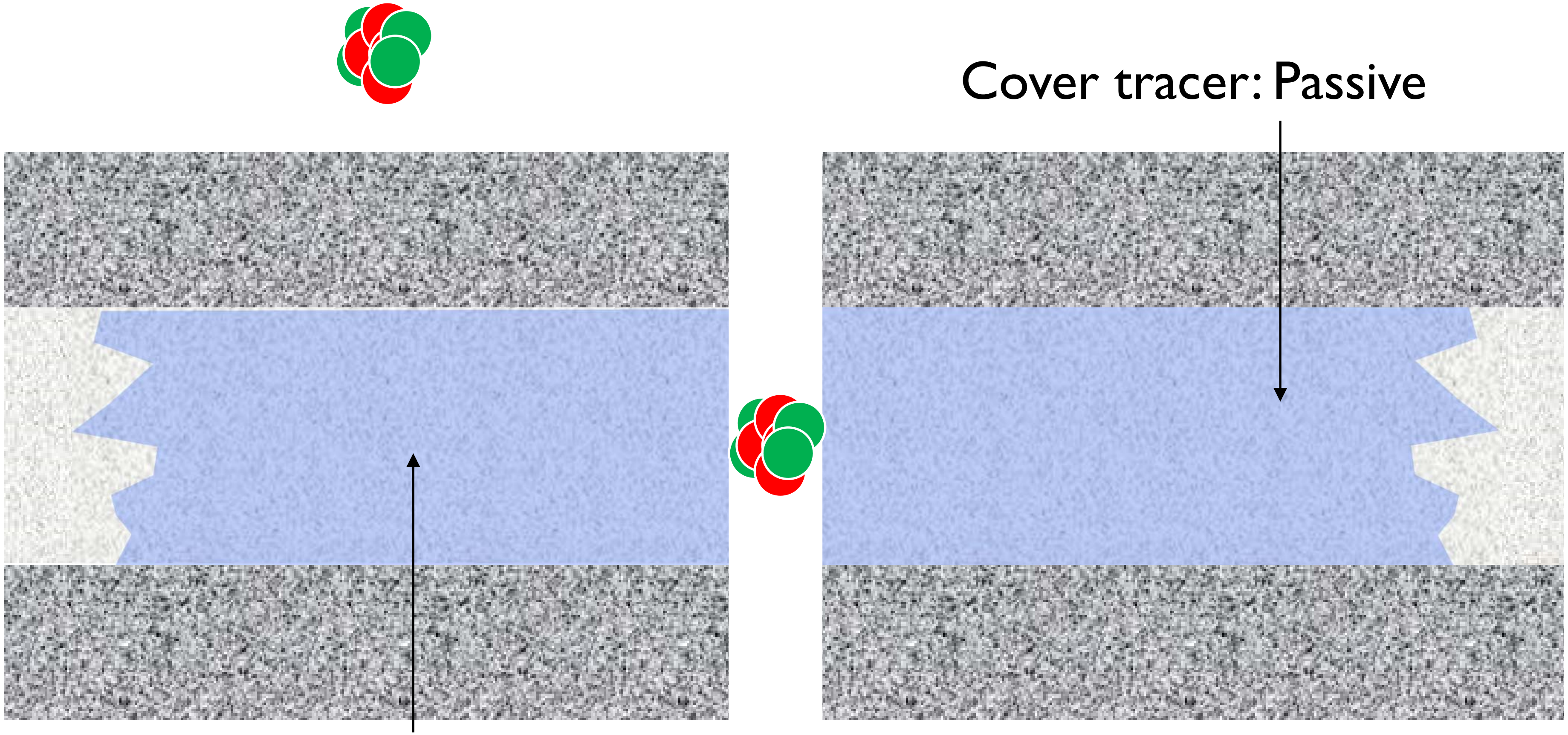
SWCTT principle

Chemical reaction

Hydrolysis reaction



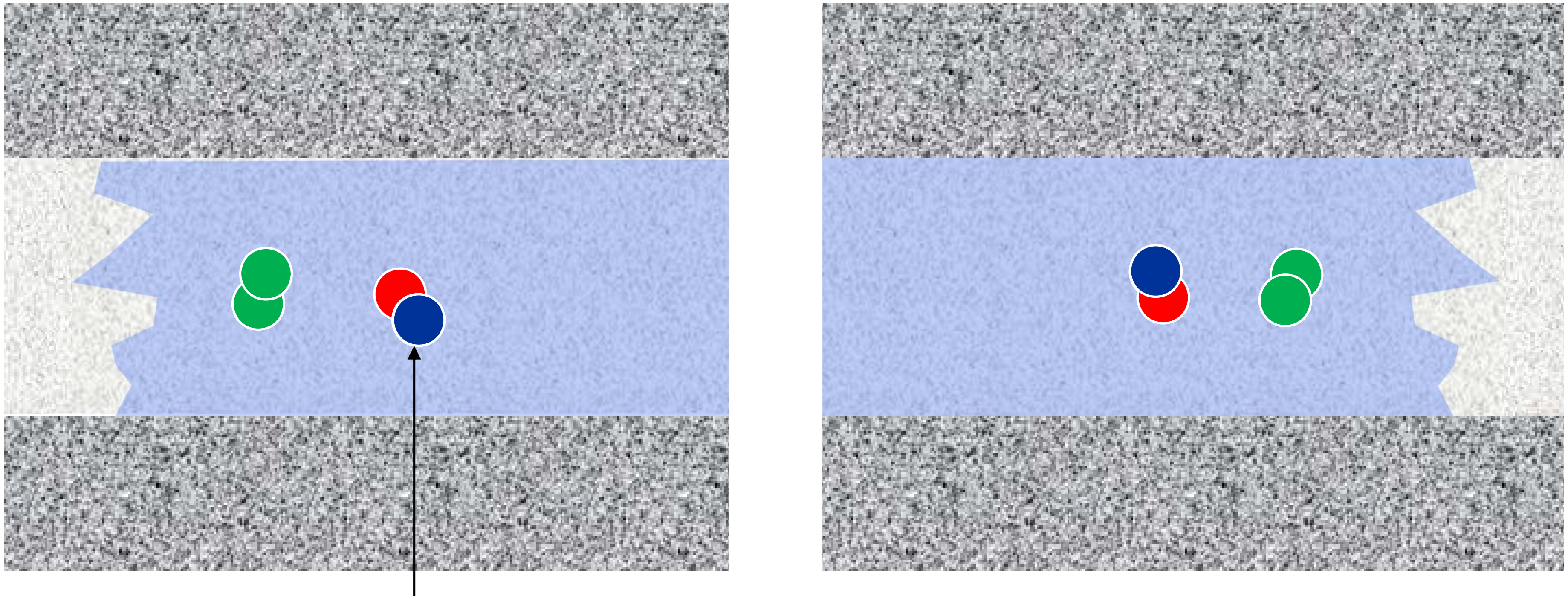
SWCTT stage 1: Injection



Cover tracer: Passive

Partitioning and reacting tracer: Ester

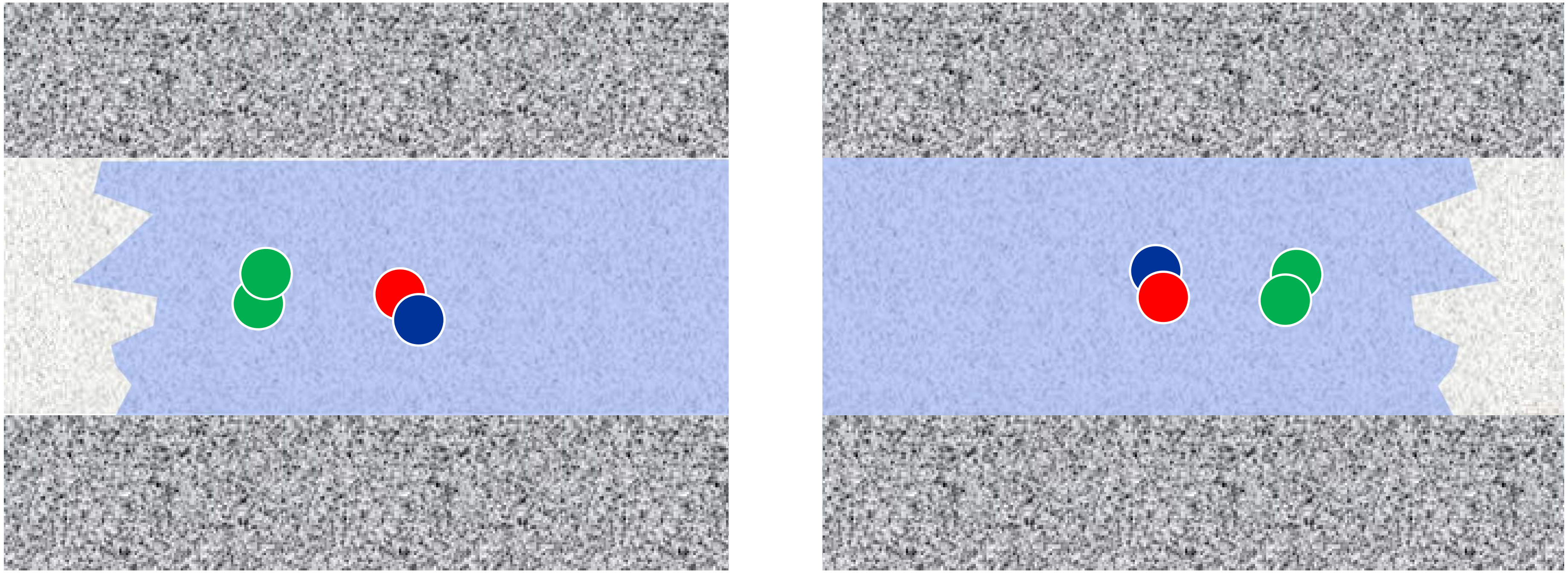
SWCTT stage 2: Shut-in with hydrolysis



Formed alcohol water tracer

SWCTT stage 3: Back-production

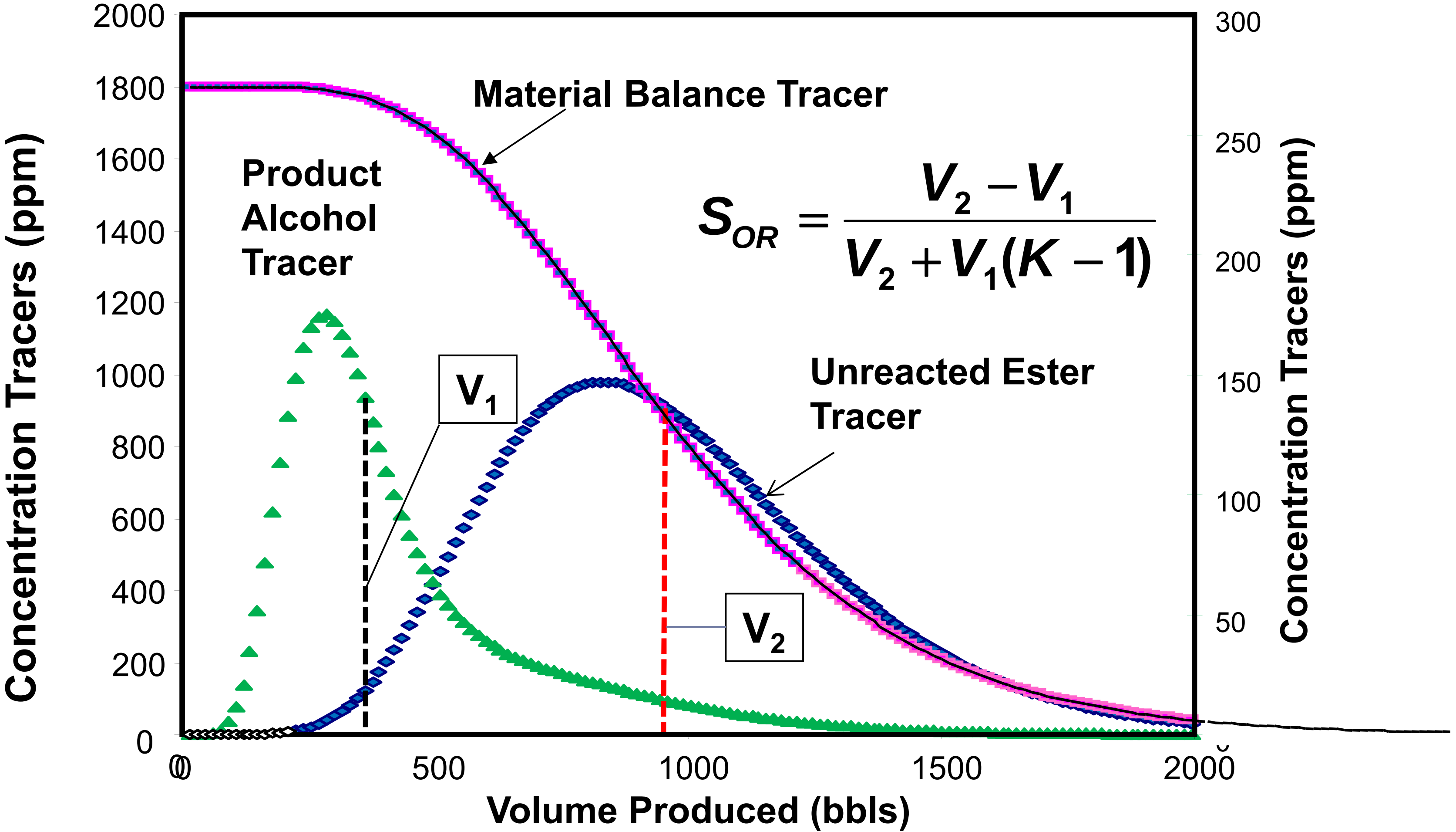
To analysis



SOR ∝ Distance (in time/volume) between remaining ester and produced alcohol tracers.

Single Well Chemical Tracer Test

Production Curve



$$S_{OR} = \frac{V_2 - V_1}{V_2 + V_1(K - 1)}$$

IRIS

Universitetet i Stavanger

IFE

Single Well Chemical Tracer Test

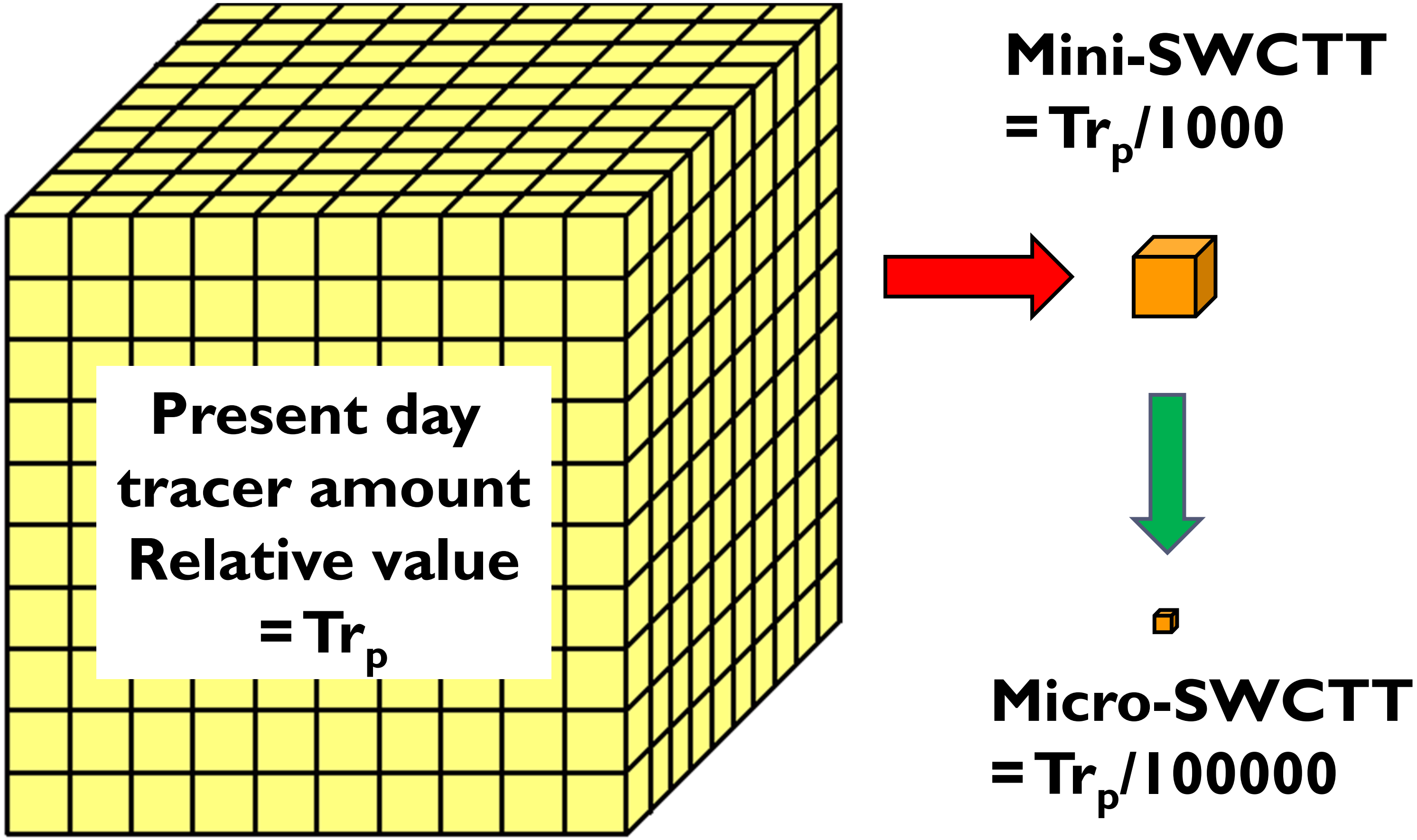
New developments

IOR center Task 5: Tracer technology:

Main work packages:

- **Further development of PITT technology:**
    - New phase-partitioning tracers
    - Lab. studies on stability
    - Field pilots
- **Further development of SWTT technology:**
    - New concepts including esters and other water-reacting compounds
    - Miniaturization of field process (two steps)
- **Introduction of «smart» nanoparticle tracers for both PITT and SWTT**
- **Improved modeling and interpretation methods**

New SWCTT development:
Tracer volume reduction

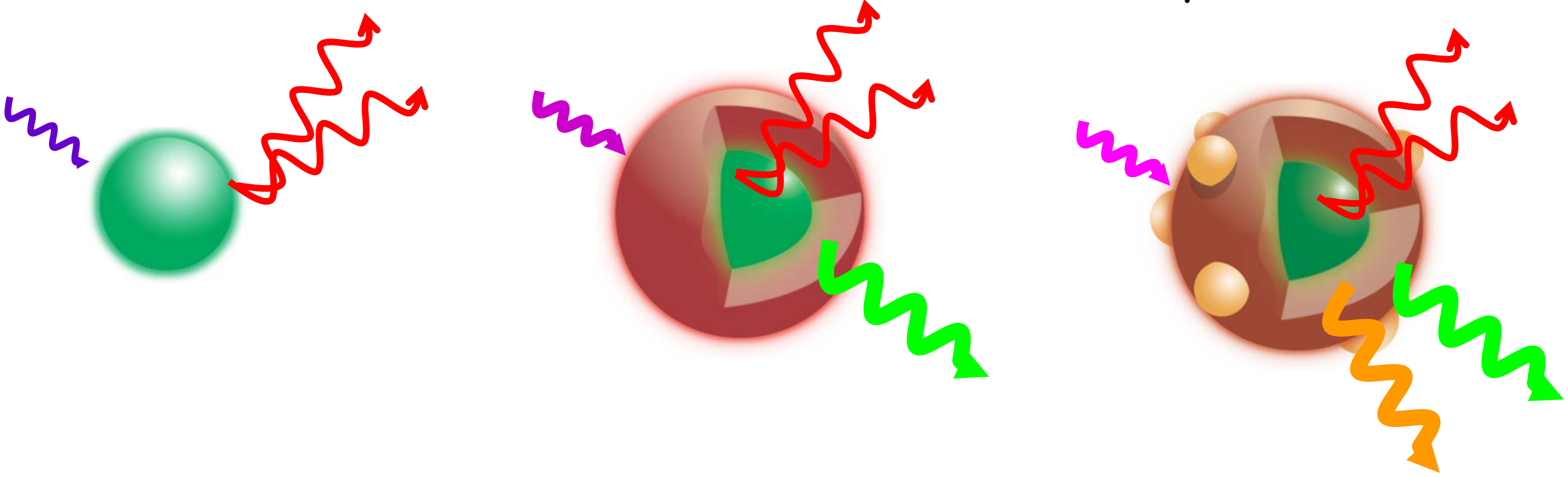


Present day tracer amount Relative value = Tr_p

Mini-SWCTT = $Tr_p/1000$

Micro-SWCTT = $Tr_p/100000$

Fluorescent and Radioactive Nano-Particles for both IWPTT, RITT SWPTT and SWRTT



Particle core emission

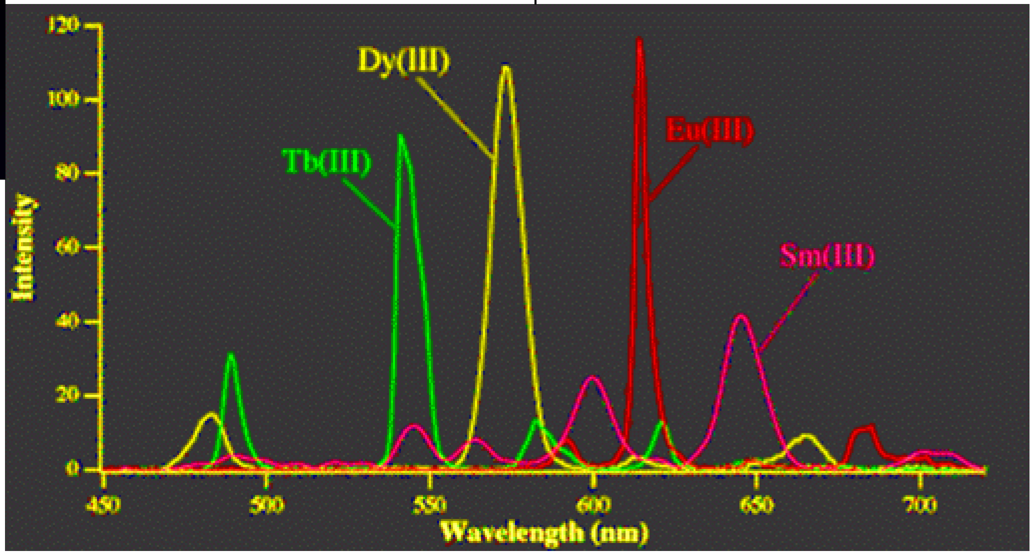
Particle core and functional layer emission

Particle core and multifunctional layer emission

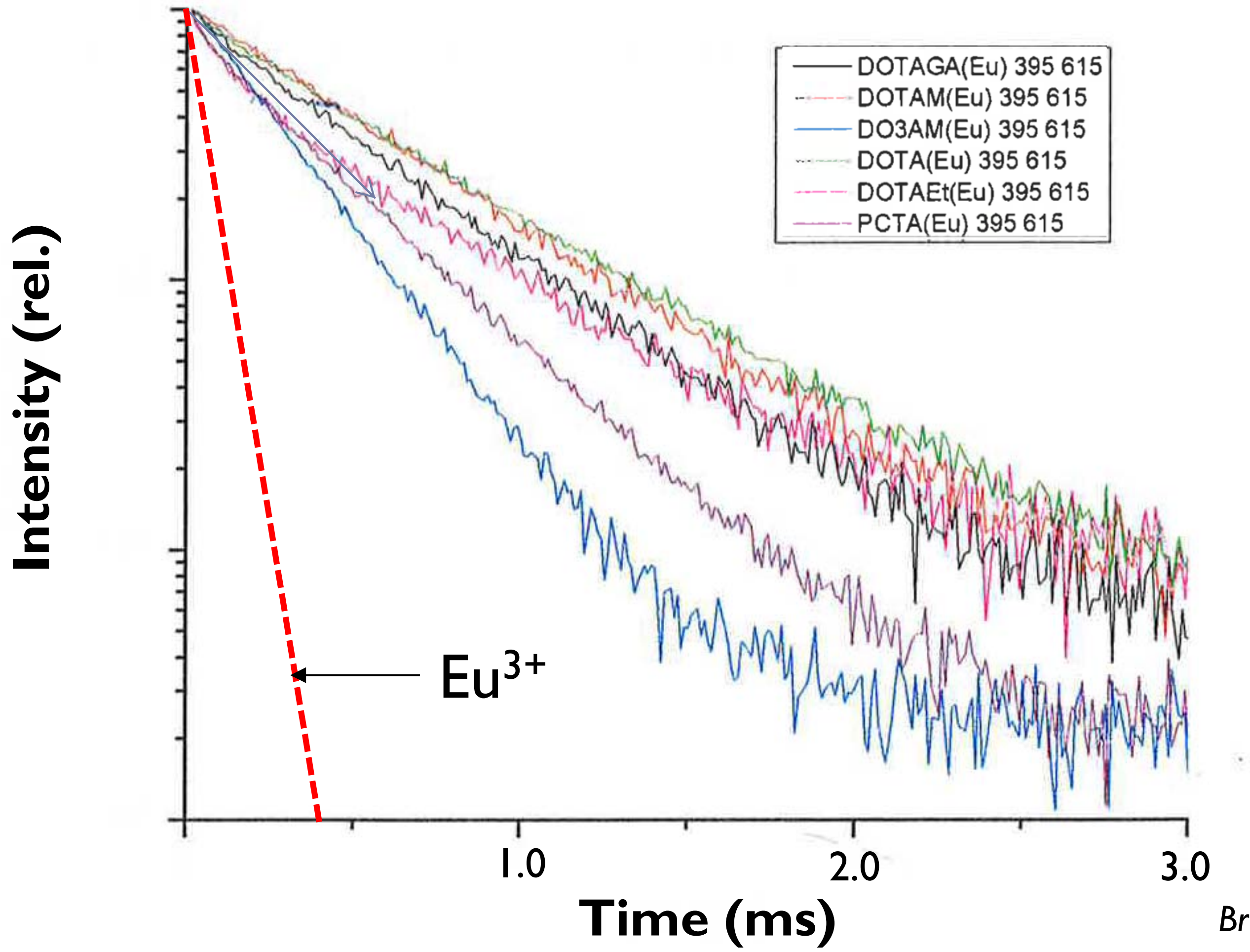
Fluorescense of rare earth metals

Fluorescence colors of selected rare earths

Fluorescence spectra of selected rare earths

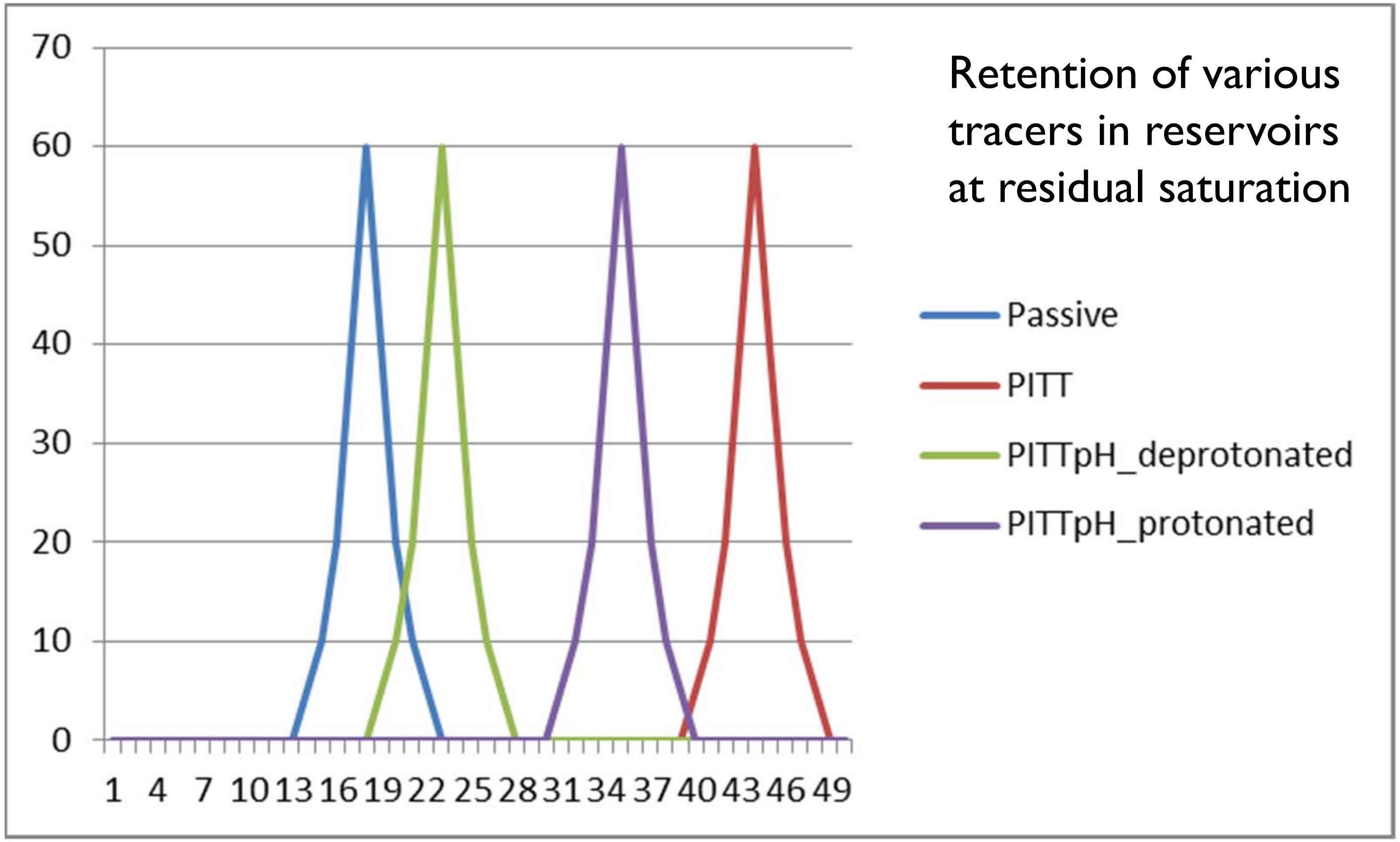


Fluorescens decay-time of various Eu-complexes



Brichart, 2014

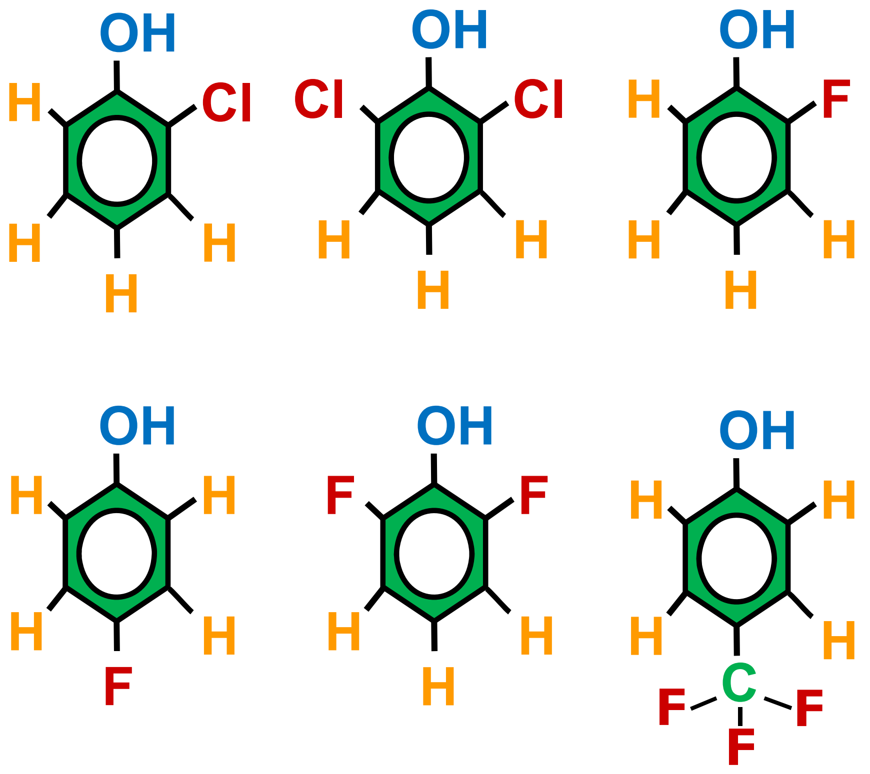
Measuring reservoir pH with «smart» tracers



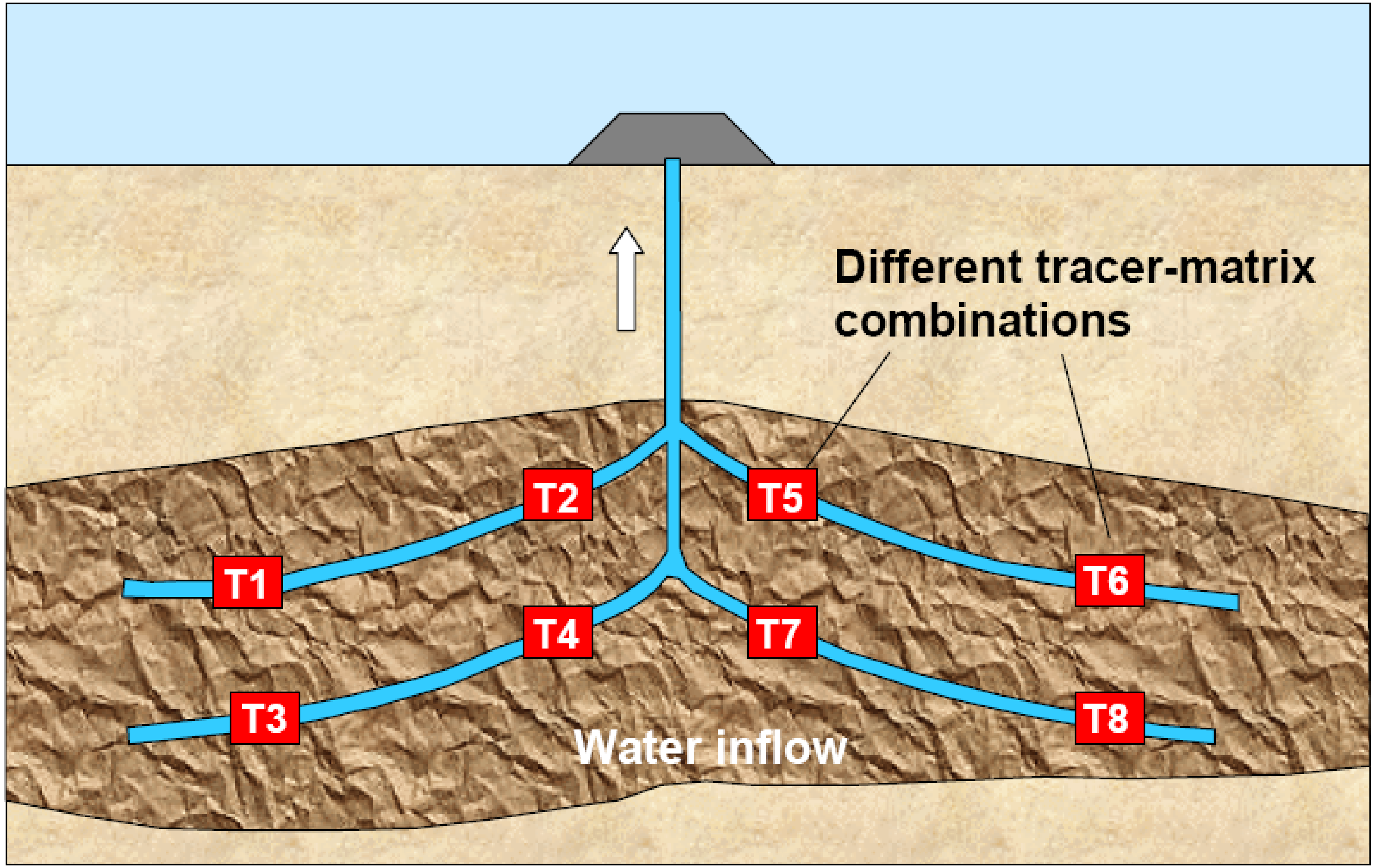
Retention of various tracers in reservoirs at residual saturation

Examples of possible tracer compounds for pH measurement

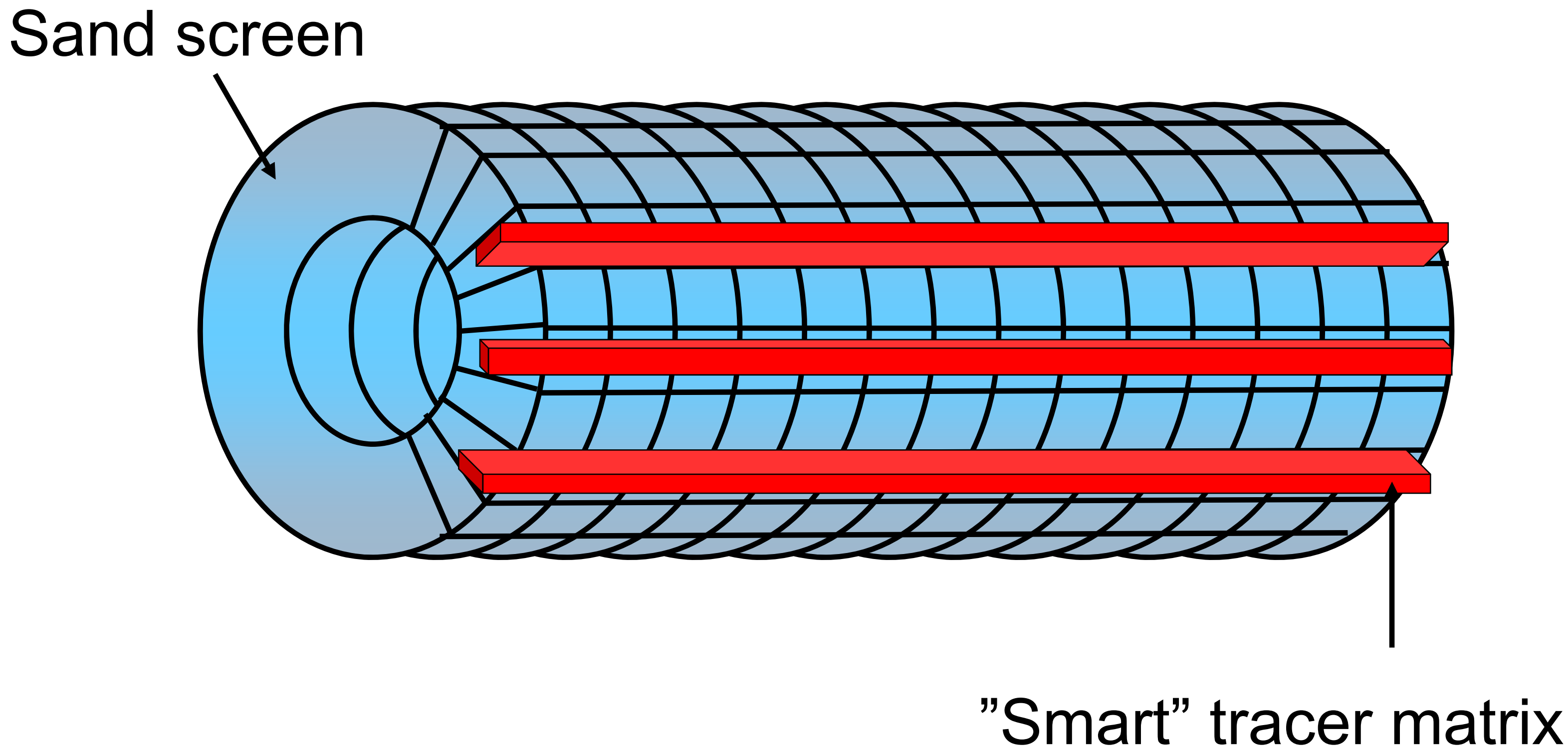
Name
2-Chlorophenol
2,6-DiChlorophenol
2-fluorophenol
4-fluorophenol
2,6-Difluorophenol
4-(Trifluoromethyl)phenol



Complex well inflow monitoring

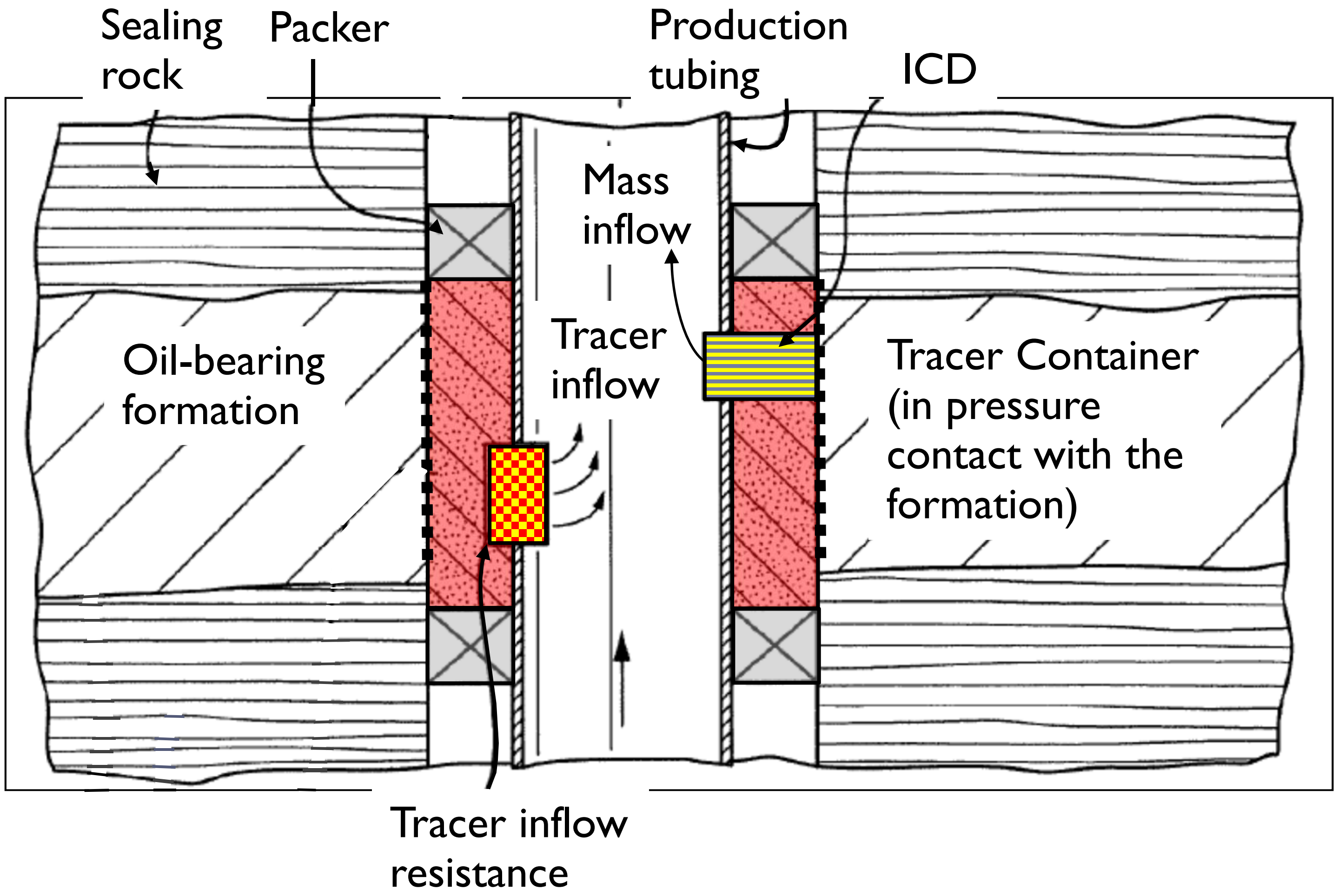


Tracers in polymer rods- placed in the sandscreen



…showing the polymer matrix

ICD- and tracer-based mass inflow monitoring



Basis of the patent

The chamber 20 contains tracer compounds with a known concentration. For a given differential pressure Δp between the annulus 3 and the inside of the production tubing, the rate of flow of tracer F_{trac} from the tracer reservoir can be described as:

$$F_{trac} = \frac{k \cdot c_{trac}}{\mu} \cdot \Delta p$$

Here, k is a constant related to the characteristics of the flow resistance element representing the inverse of the flow resistance, c_{trac} is the known tracer concentration in the tracer reservoir and μ is the known viscosity of the tracer liquid at the prevailing temperature. The tracer flow, F_{trac} (amount of tracer/time unit) is thus proportional to the differential pressure between the tubing 10 and annulus 3, and the proportionality constant can easily be determined.

Basis of the patent cont.

The same amount of tracer which enters the production tubing from the tracer reservoir will exit the production tubing topside (tracers are selected so that there is no tracer degradation of the tracer or sorption to the tubing wall during transport). Let the volumetric flow topside be V_{top} (production flow) and let the tracer concentration in the fluid topside be c_{top}. Then, we have:

$$V_{top} \cdot c_{top} = F_{trac} = \frac{k \cdot c_{trac}}{\mu} \cdot \Delta p$$

$$\Delta p = \frac{V_{top} \cdot c_{top} \cdot \mu}{k \cdot c_{trac}}$$

Basis of the patent cont.

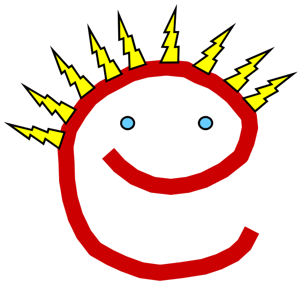
- One observes that **k**, $\mathbf{c_{trac}}$ and μ are known (measured in the lab). The total production volume per time unit $\mathbf{V_{top}}$ is also known (measured at the platform). Thus, $\mathbf{c_{top}}$ may be determined by collecting fluid samples followed by tracer analysis. Thus, $\Delta\mathbf{p}$ can be calculated accurately.

- Knowing $\Delta\mathbf{p}$ and the flow resistance characteristics of the ICD, the production flow entering the tube at the production zone where the tracer release device is installed can be calculated.

Great Simple Formulas

$K = ma$ (Newton)

$E = mc^2$ (Einstein)

$\mathrm{IOR} =$  $= (m^2c^2)xf(x,y,..)$

Efficiency = manpower x method x co-operation x co-ordination