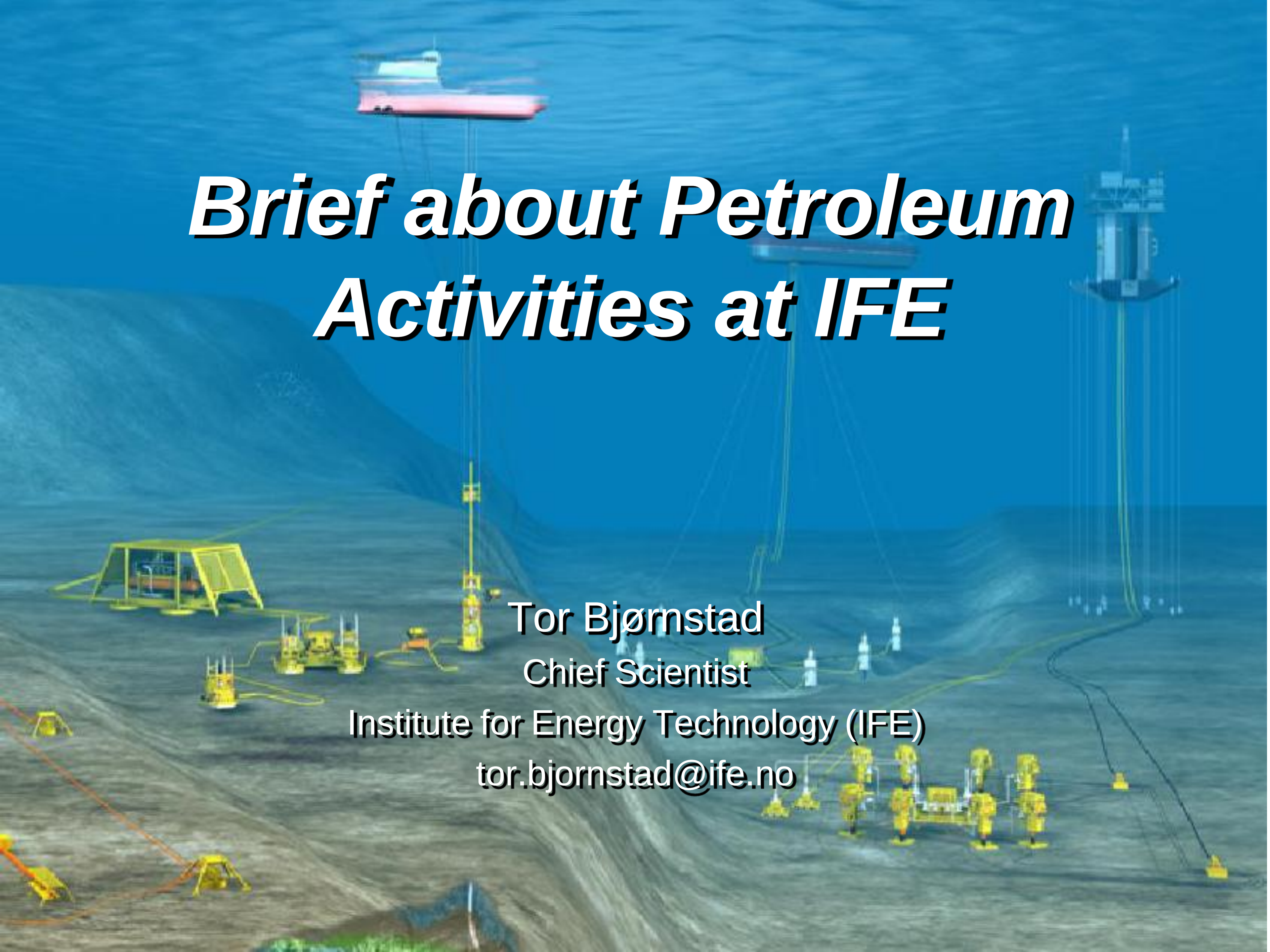

Brief about Petroleum Activities at IFE

Tor Bjørnstad

Chief Scientist

Institute for Energy Technology (IFE)

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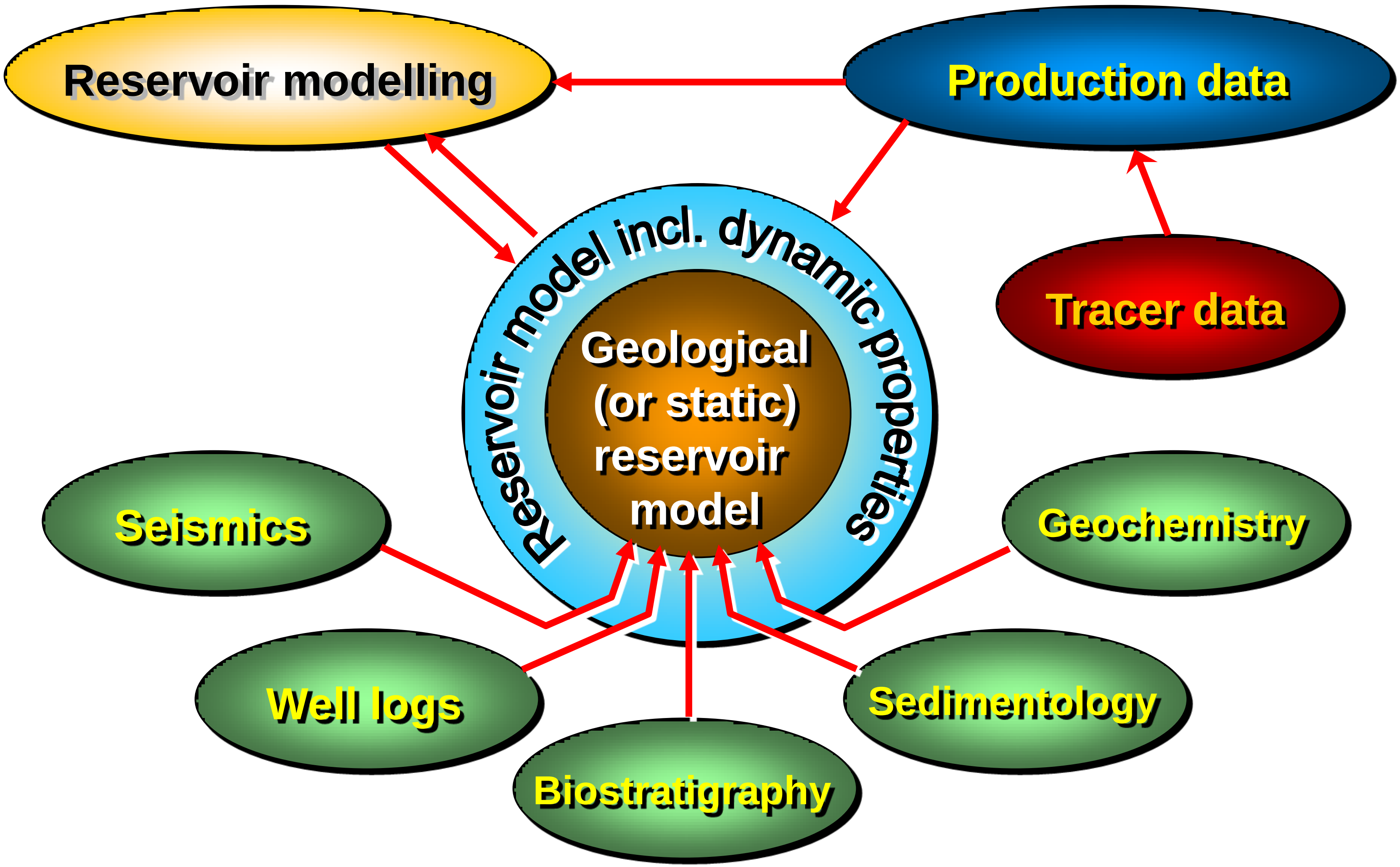
Subjects not to be treated here

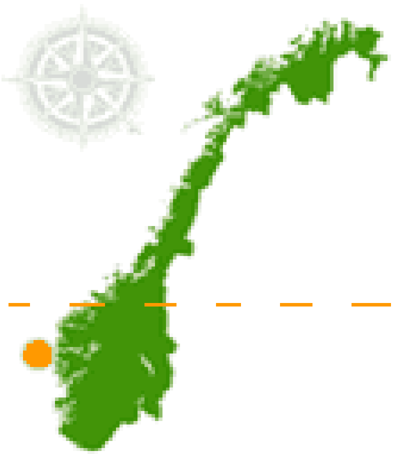
- Multiphase flow in wells and pipelines (OLGA etc.)
- CO_2 and H_2S corrosion in transportation systems
- Hydrate prevention (MEG-technology) and most other flow assurance aspects
- Geology/geochemistry/diagenesis/stable isotope signatures
- Micropaleontology/biomarkers/production allocation
- Basin modelling
- CCS
- Application of tracer technology during exploration

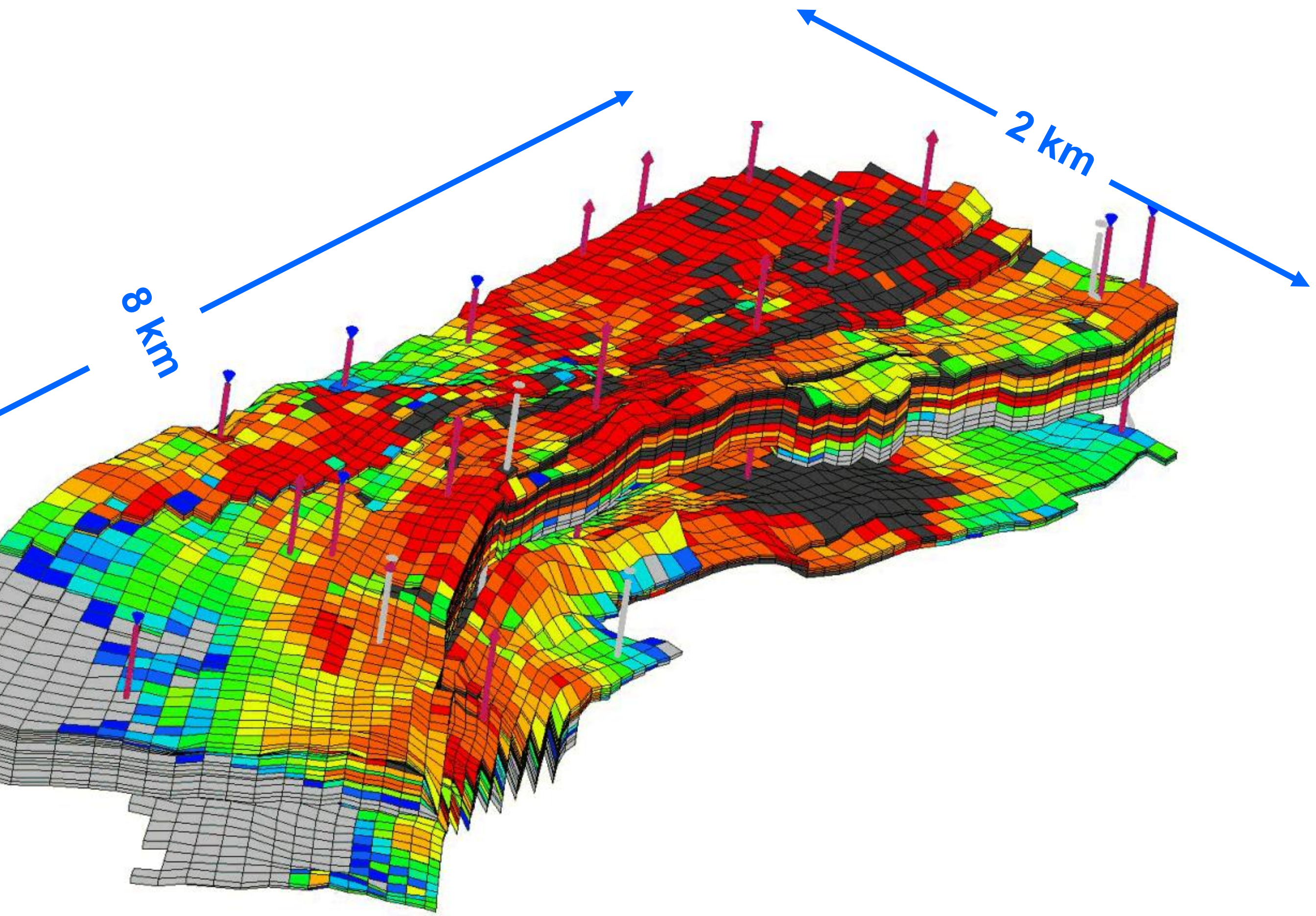
Reservoir evaluation

Reservoir characterization



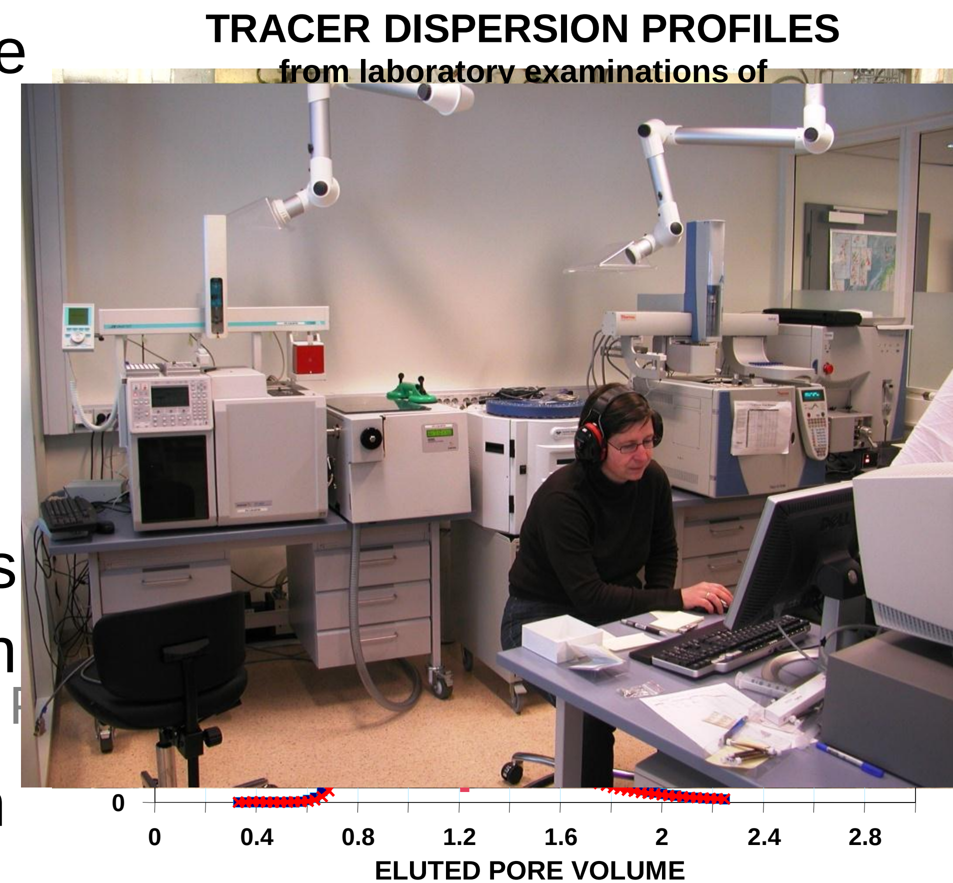
Water expelling oil –should be traced





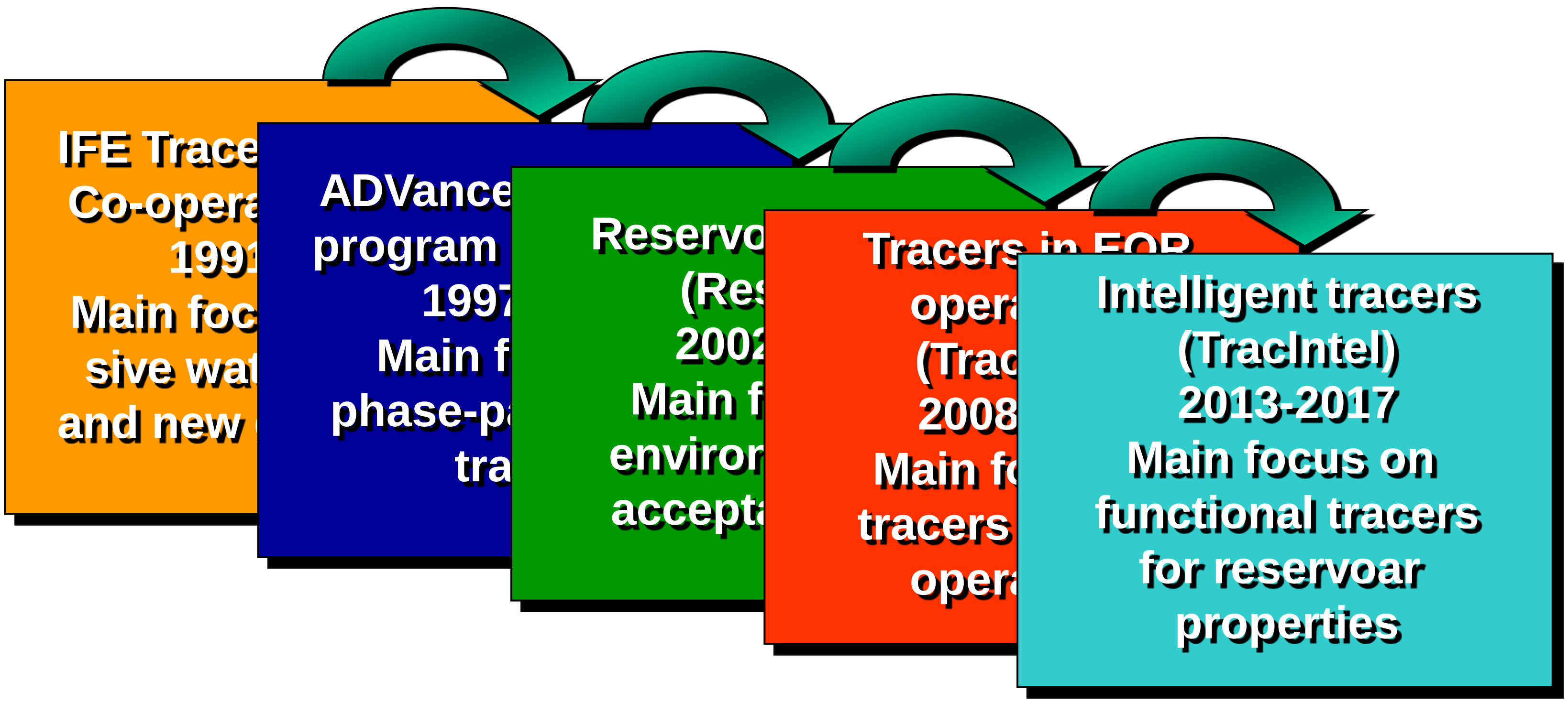
Tracer Technology Research Themes

- Development of radioactive and chemical tracers.
- Testing and verification in laboratory experiments
- Development of hyper-sensitive analytical techniques for tracers in highly diluted field samples
- Practical implementation in the field
- Development of simulation tools

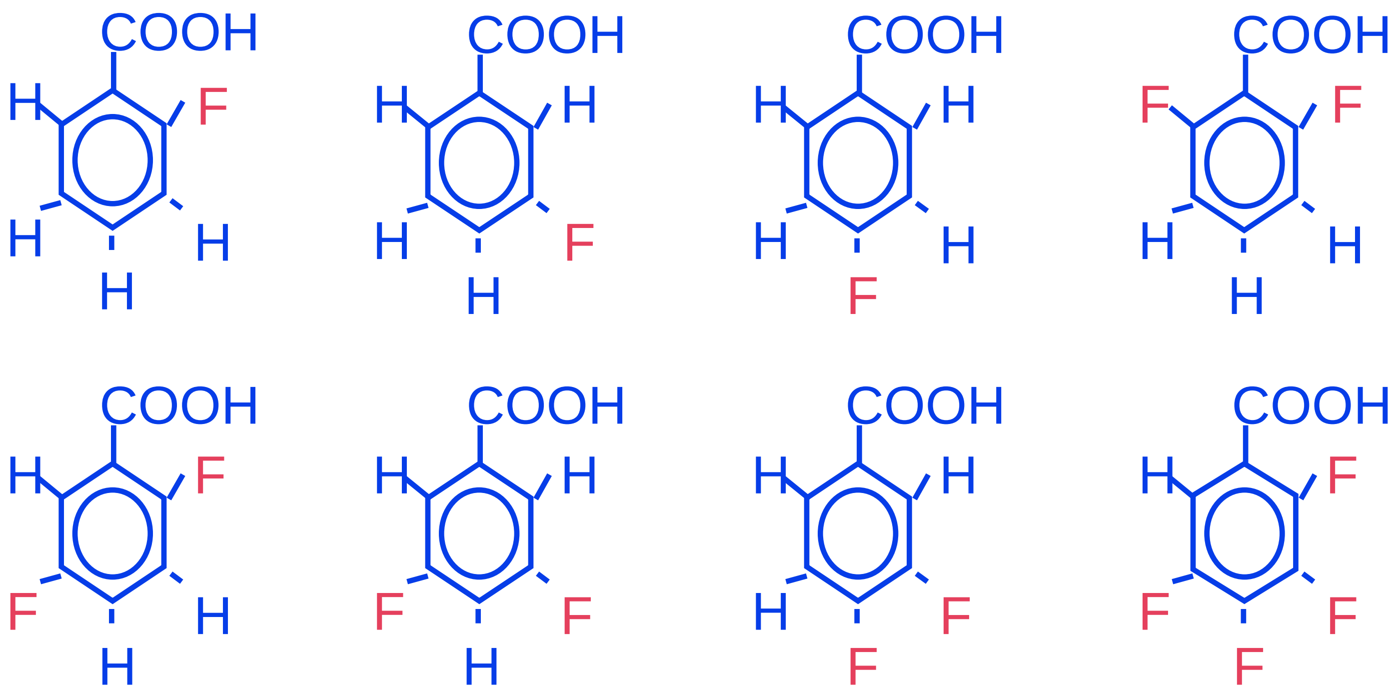


The «Tracer Club»

The ”core” of the tracer development is the ”Tracer Club” which is an industry-supported program (JIP) which are being carried out in well-defined development phases:

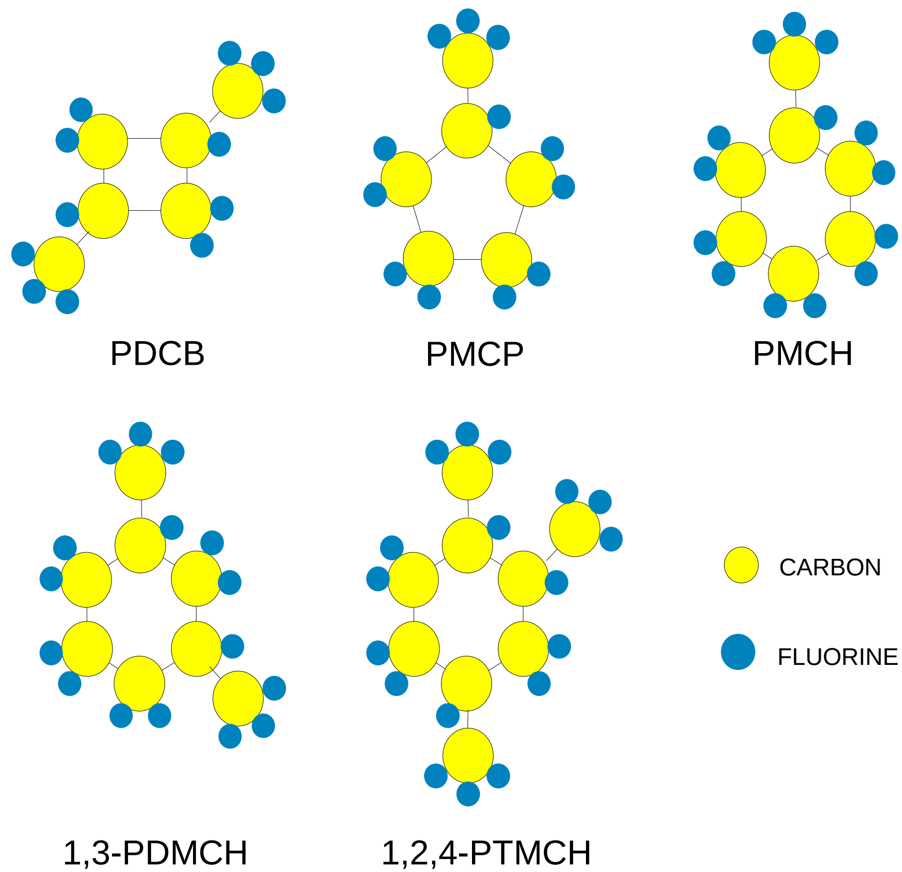


«Industry standard» interwell water tracers



“Industry standard” non-radioactive gas tracers

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

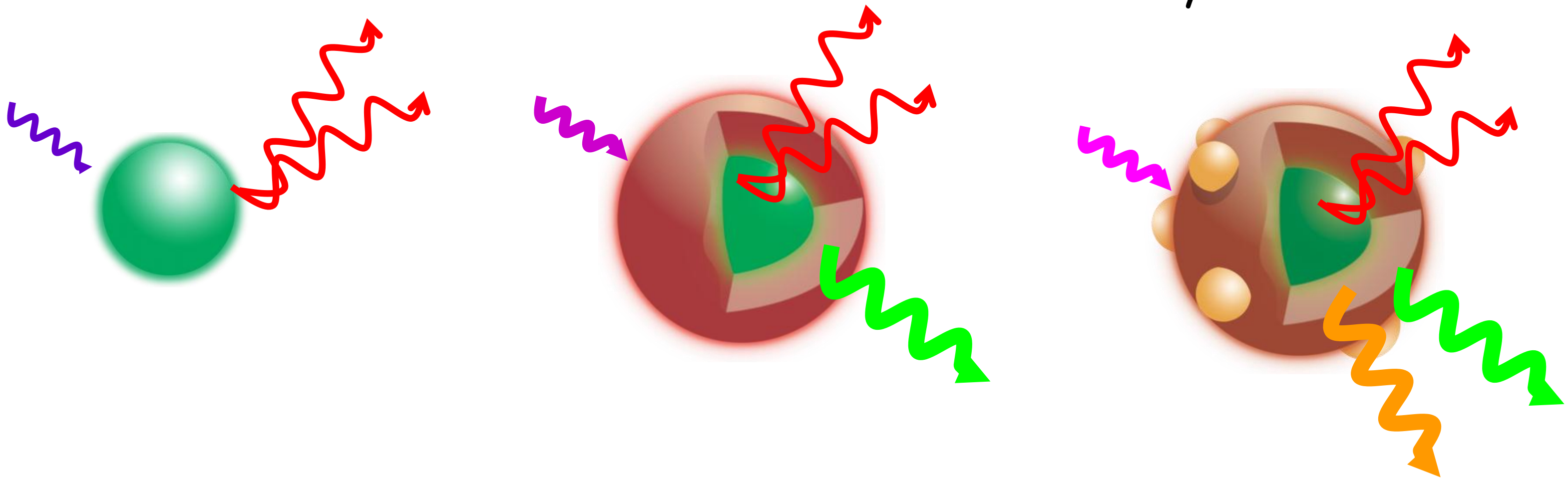


Fluorescent and radioactive nano-particles

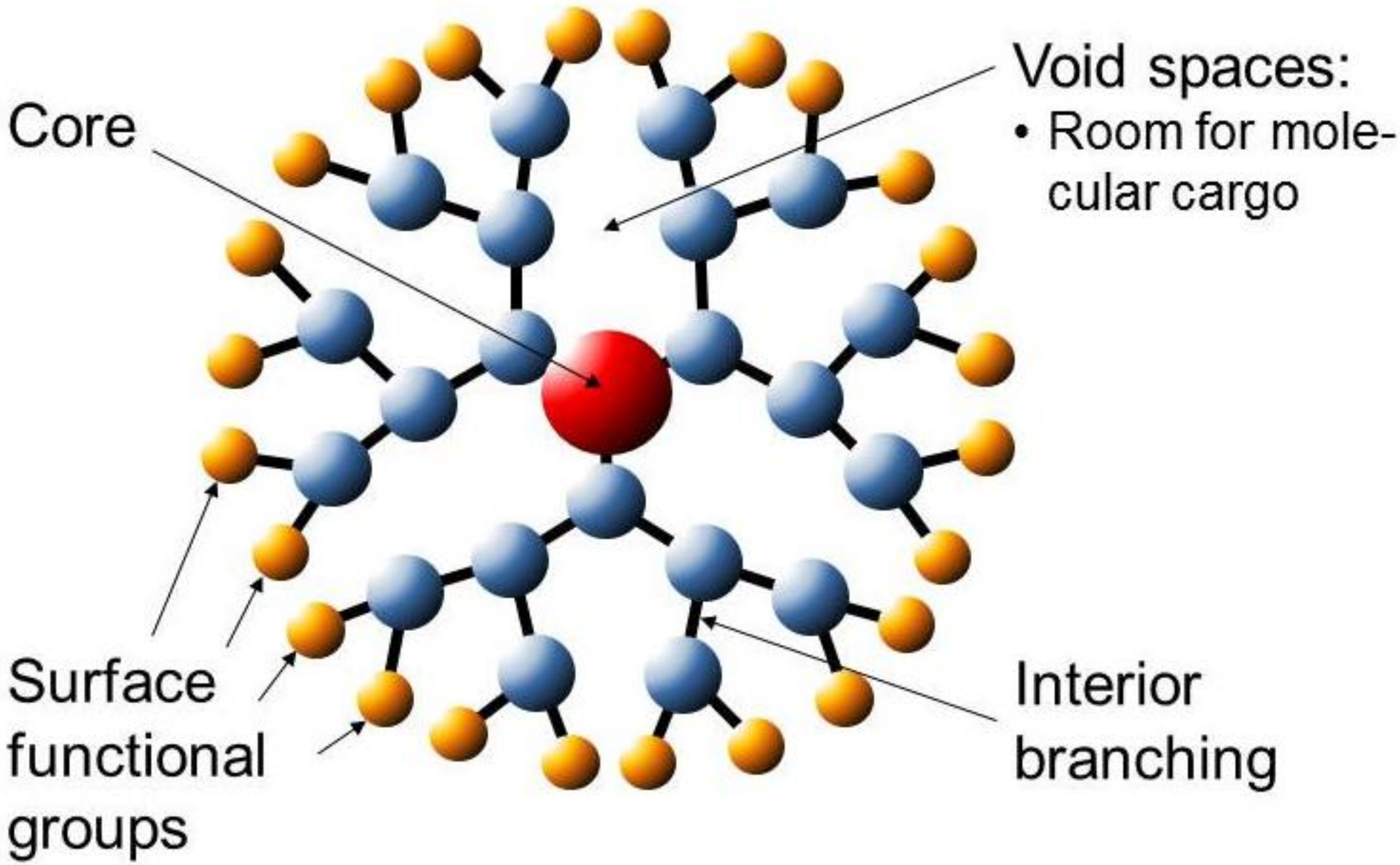
Particle core emission

Particle core and functional layer emission

Particle core and multifunctional layer emission

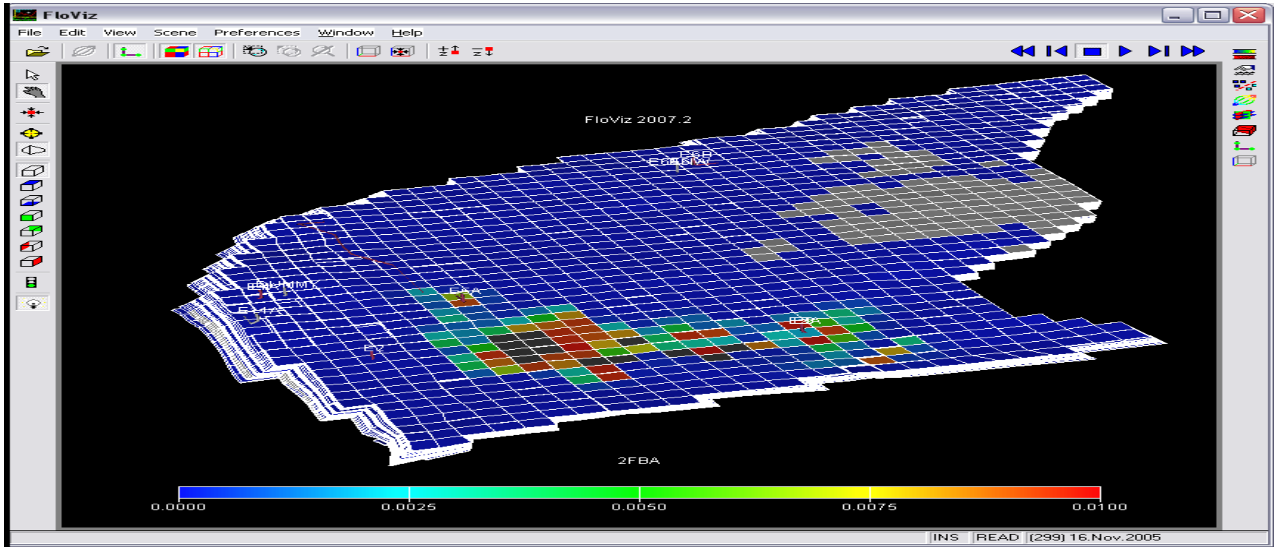


Nano-particle tracers



Interwell tracer simulator

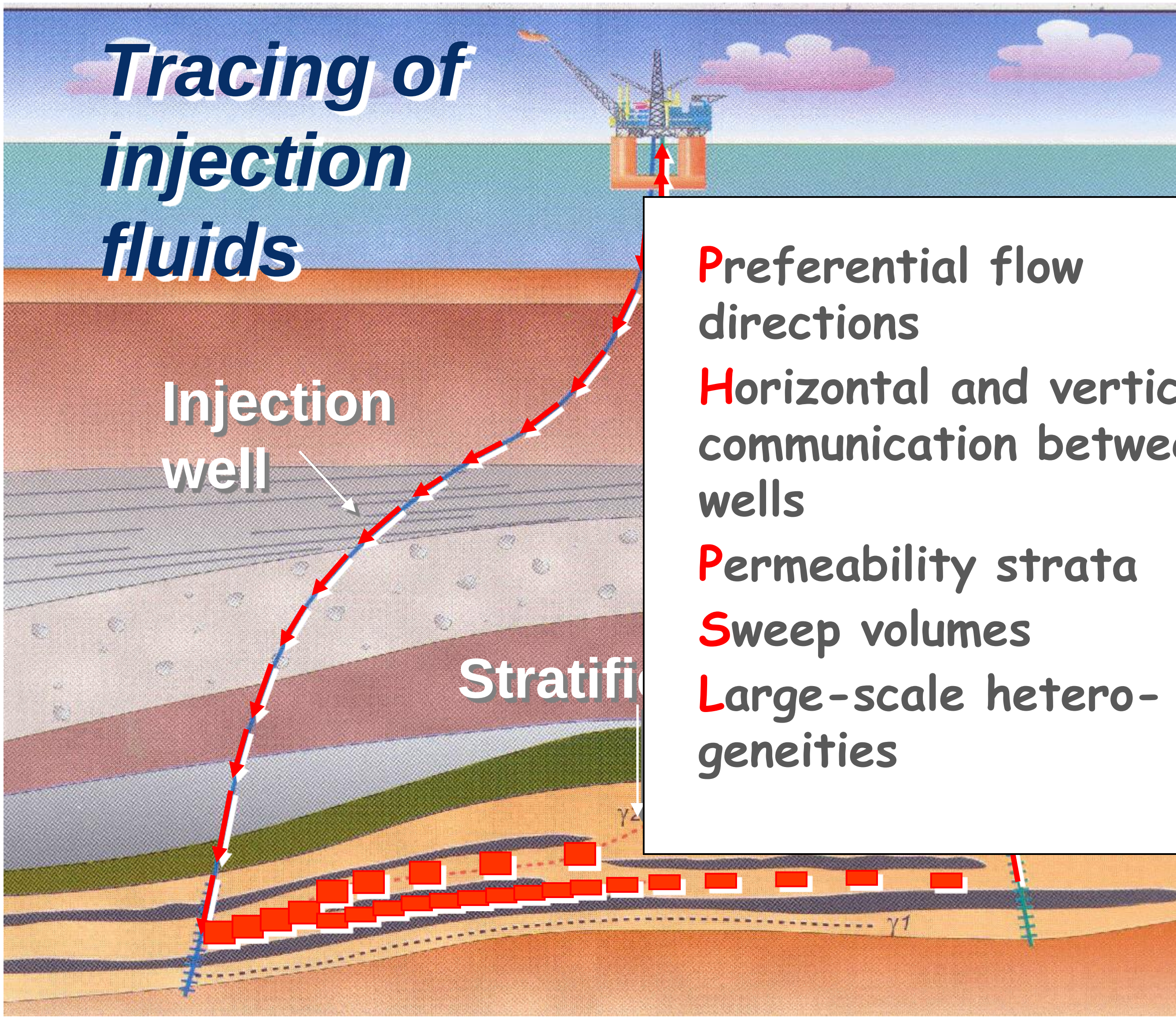
- Successful implementation of ARTSim tracer simulator
  - Tested by IFE, Statoil and Total on 5 field cases. Conclusion: very fast (5% of reservoir simulator CPU), simple to use
  - 3 journal publications, 7 conference presentations last 3 years
- Presently coupled to Eclipse E100 (black-oil) simulator



ARTSim results in FloViz (Eclipse suite visualization tool)

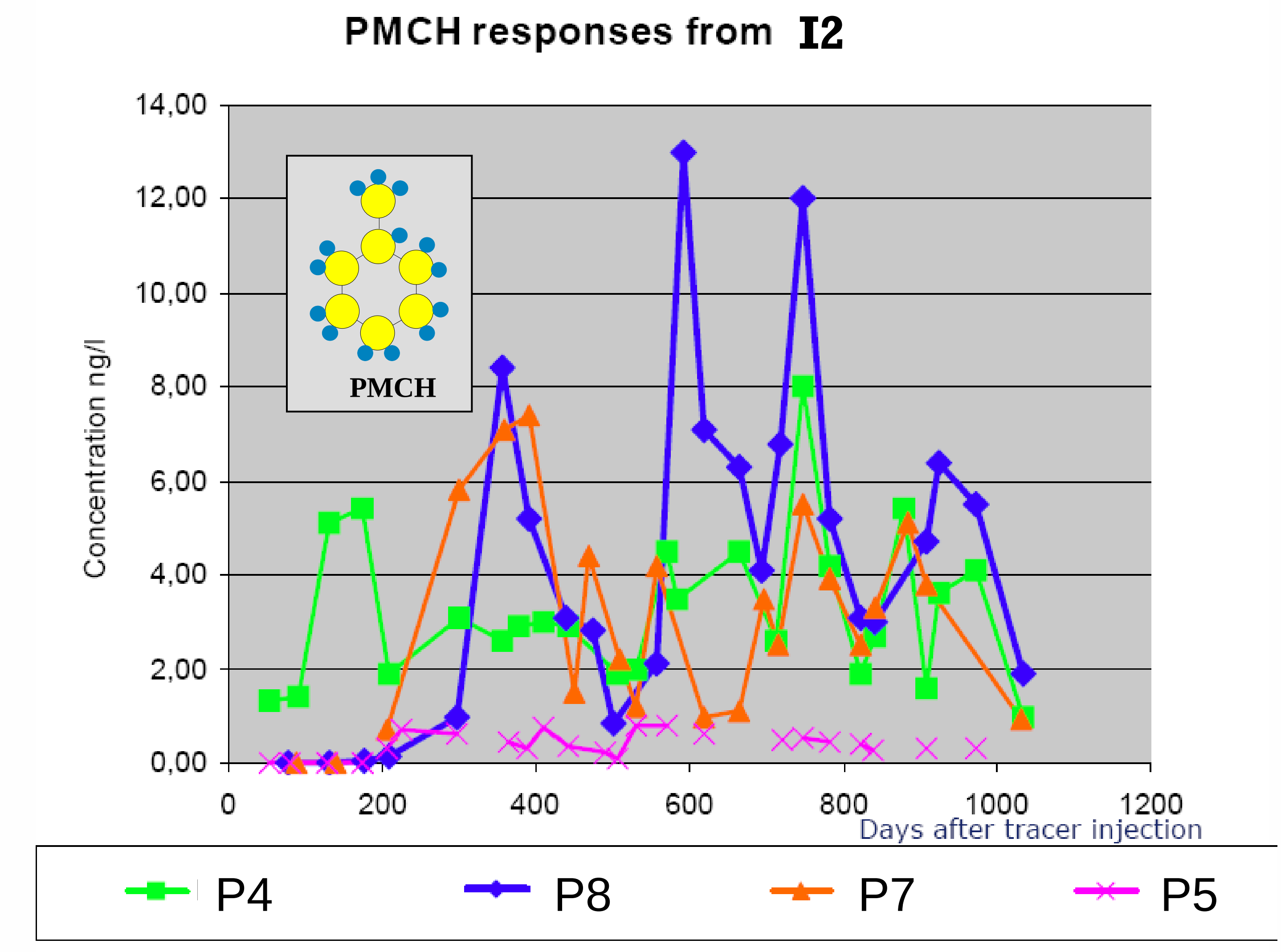
Tracers in reservoirs

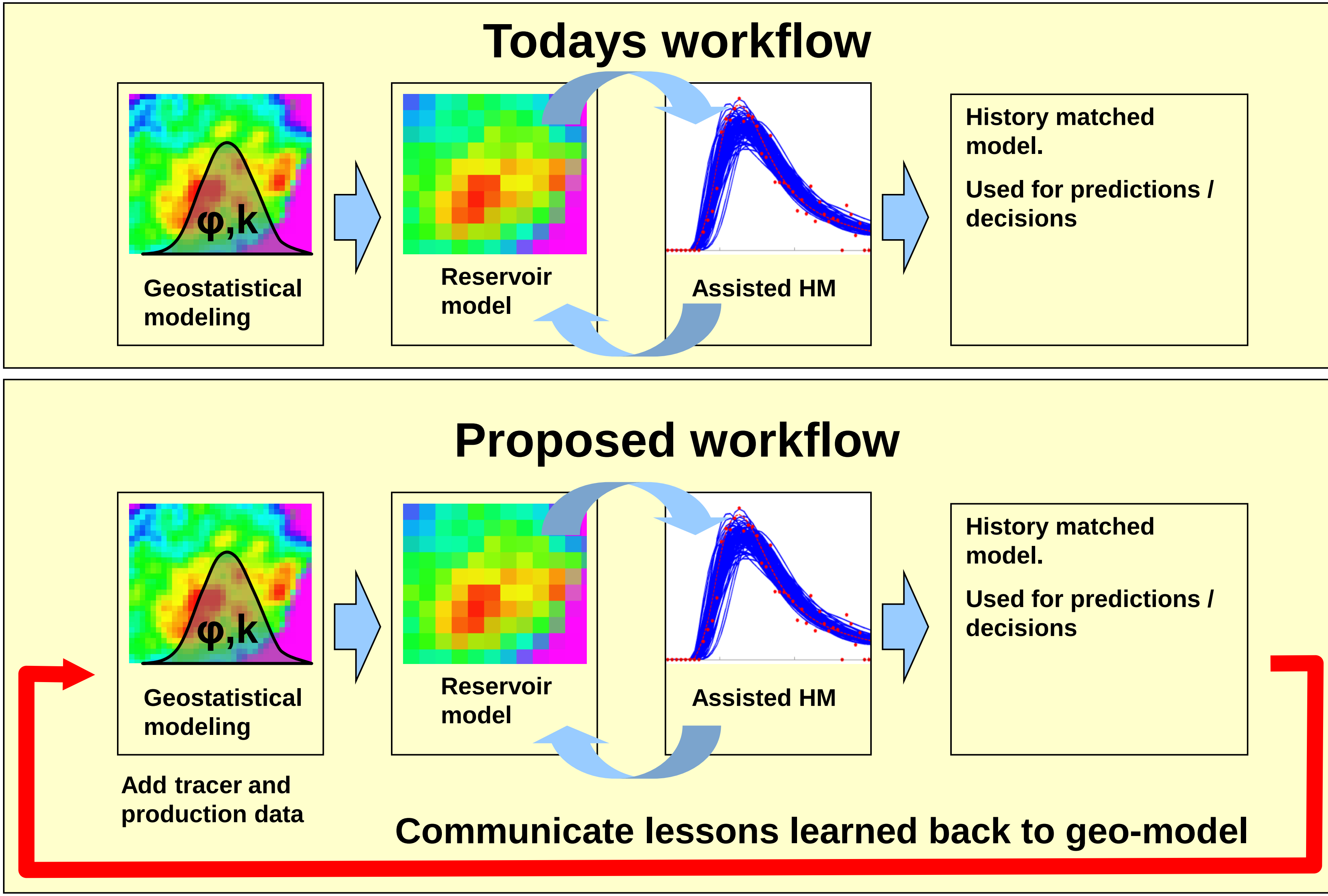
Tracing of injection fluids



- **P**referential flow directions
- **H**orizontal and vertical communication between wells
- **P**ermeability strata
- **S**weep volumes
- **L**arge-scale hetero-geneities

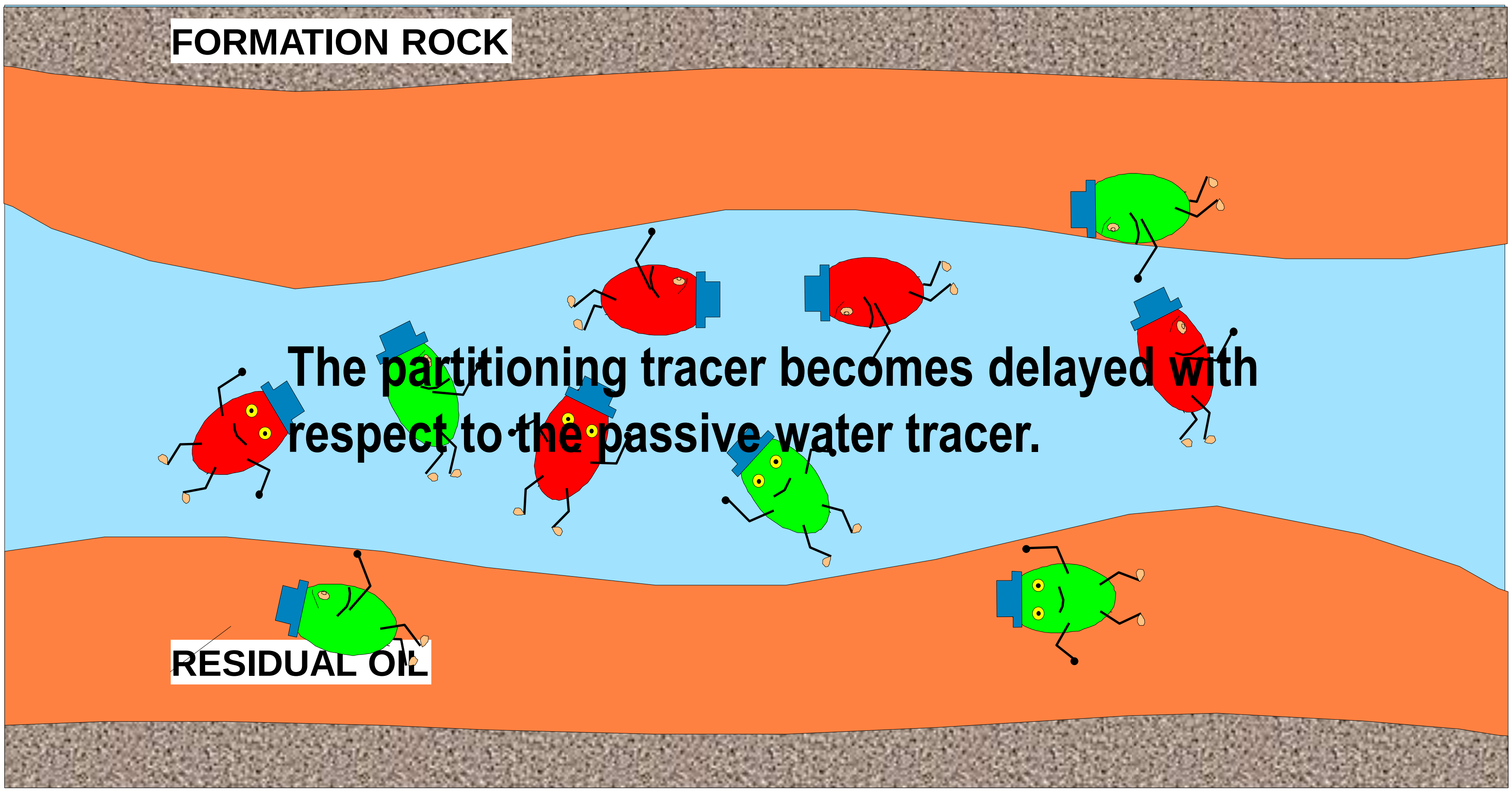
Tracer response after WAG




Todays workflow
φ,k
Geostatistical modeling
Reservoir model
Assisted HM
History matched model.
Used for predictions / decisions
Proposed workflow
φ,k
Geostatistical modeling
Reservoir model
Assisted HM
History matched model.
Used for predictions / decisions
Add tracer and production data
Communicate lessons learned back to geo-model

Remaining oil saturation

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

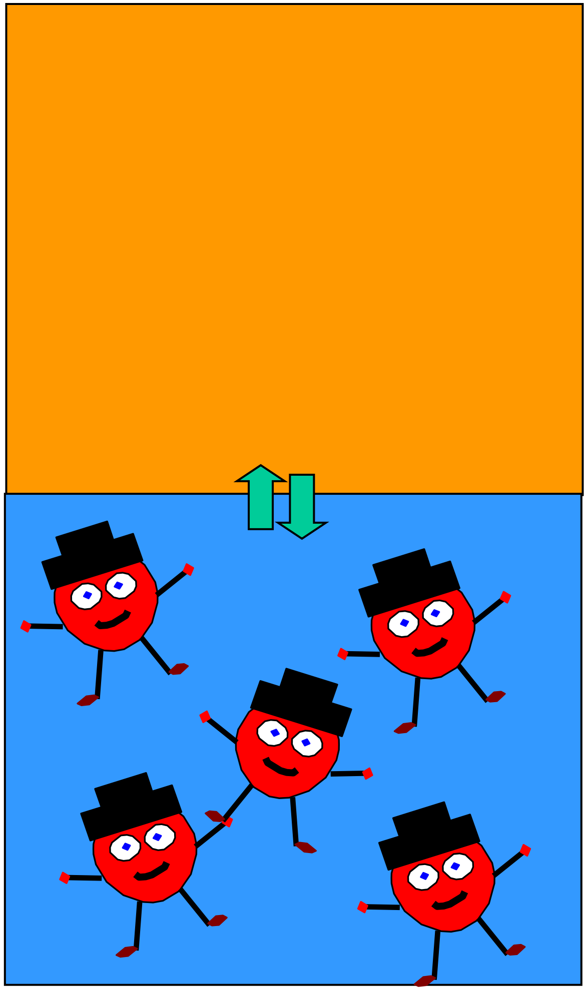


The partitioning tracer becomes delayed with respect to the passive water tracer.

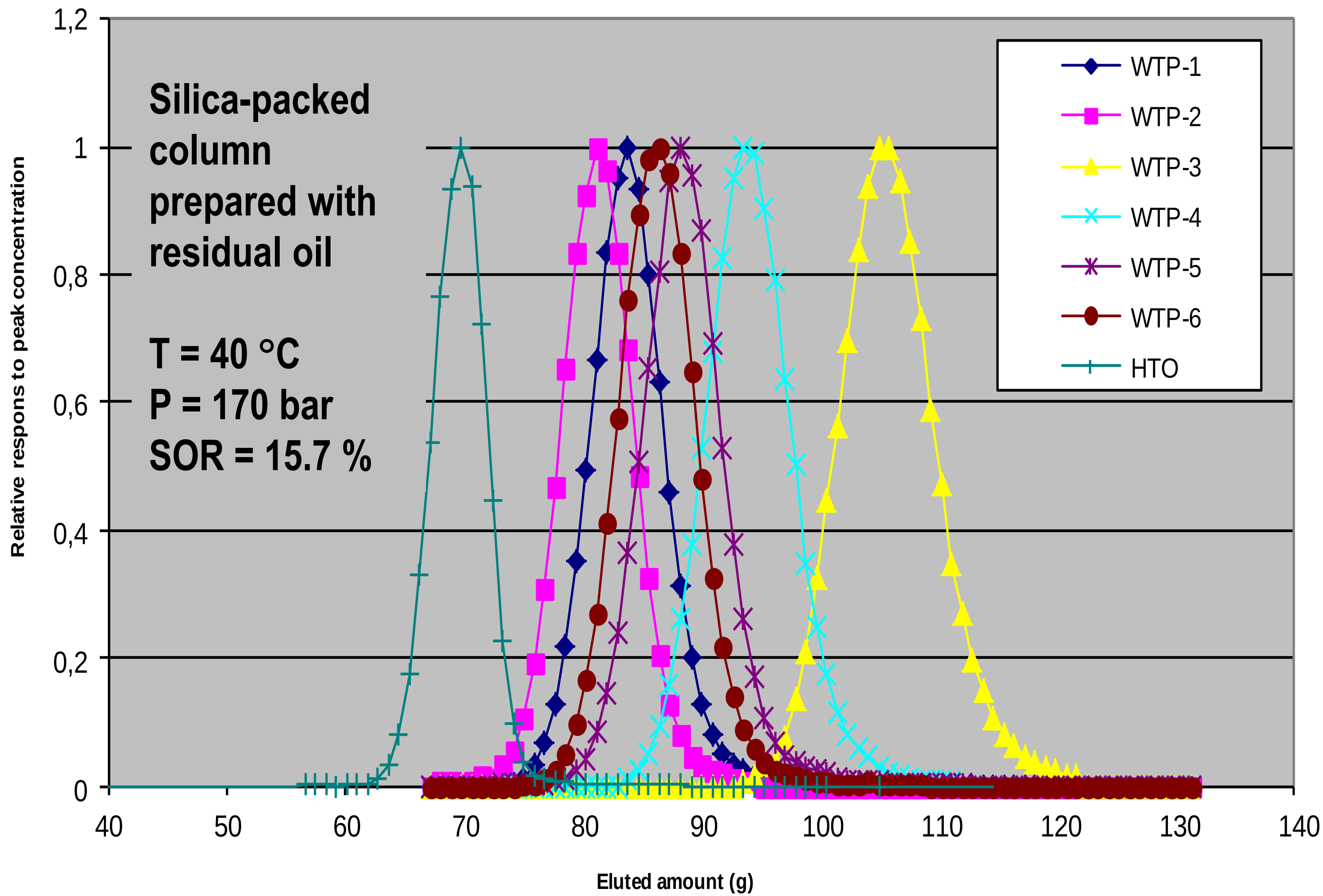
K-value (partition coefficient)

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

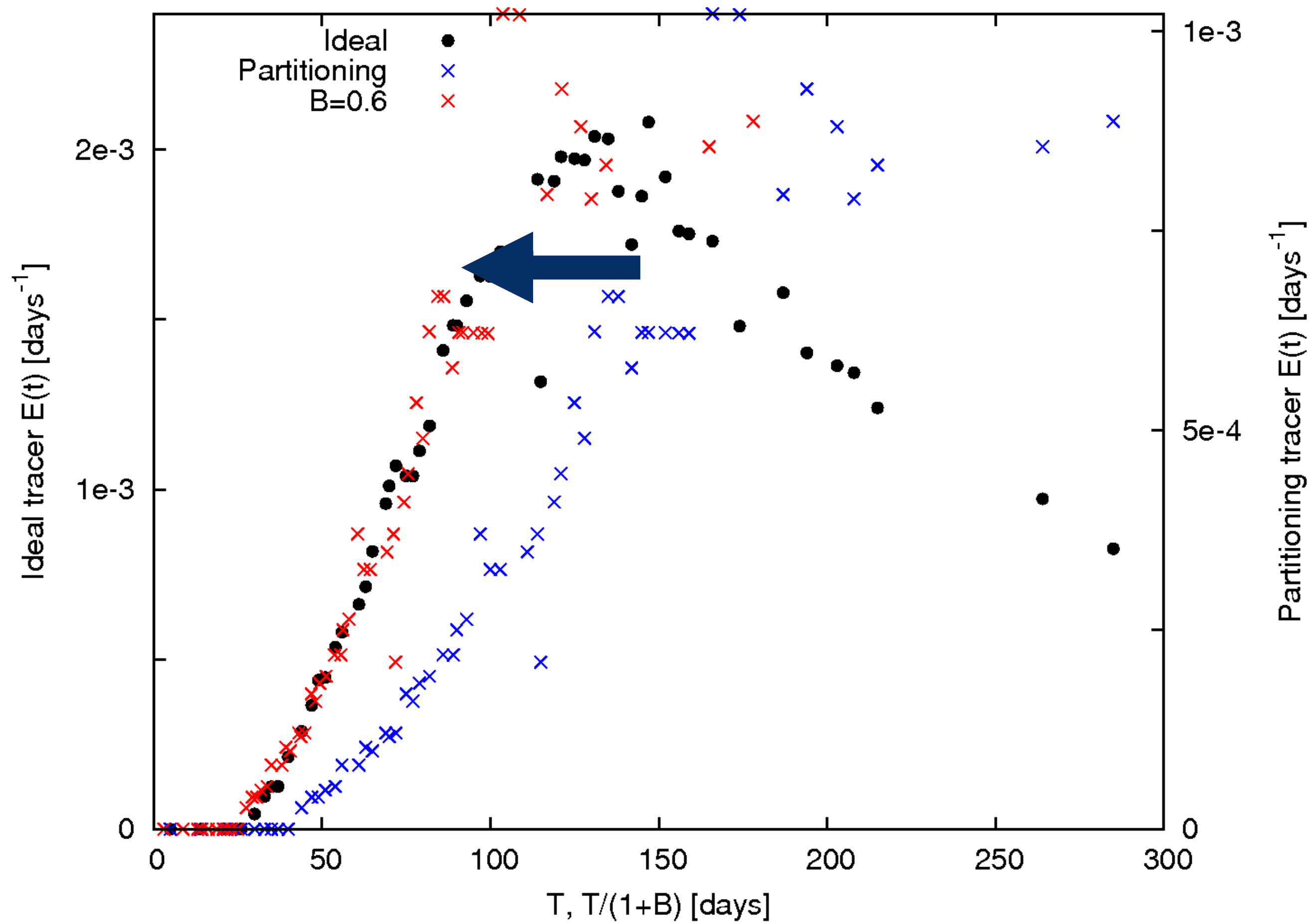
$$K = (C_{Tr})_o/(C_{Tr})_w$$



Partitioning tracer – Lab Experiments

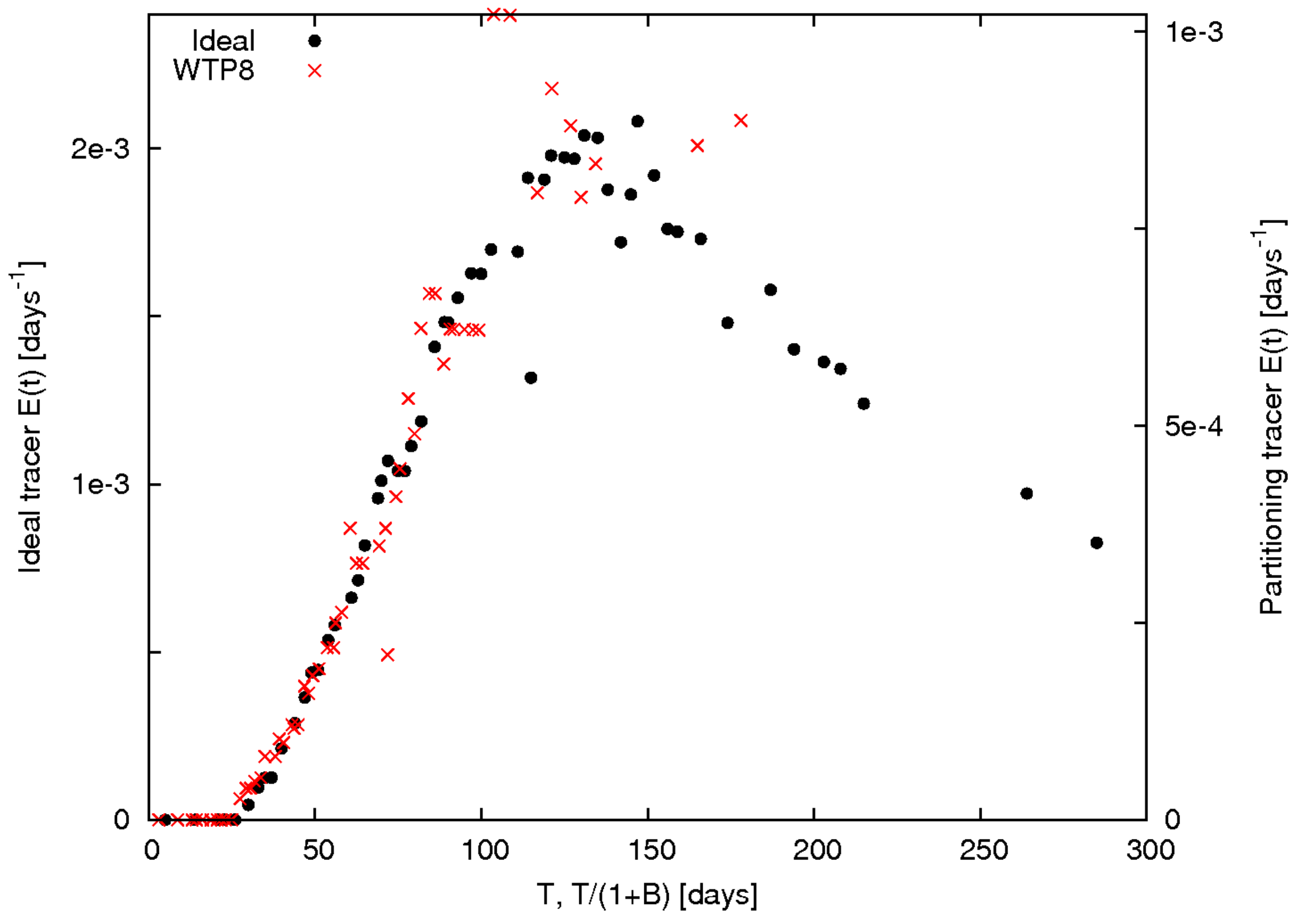


Estimation of S_o by scaling x-axis



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

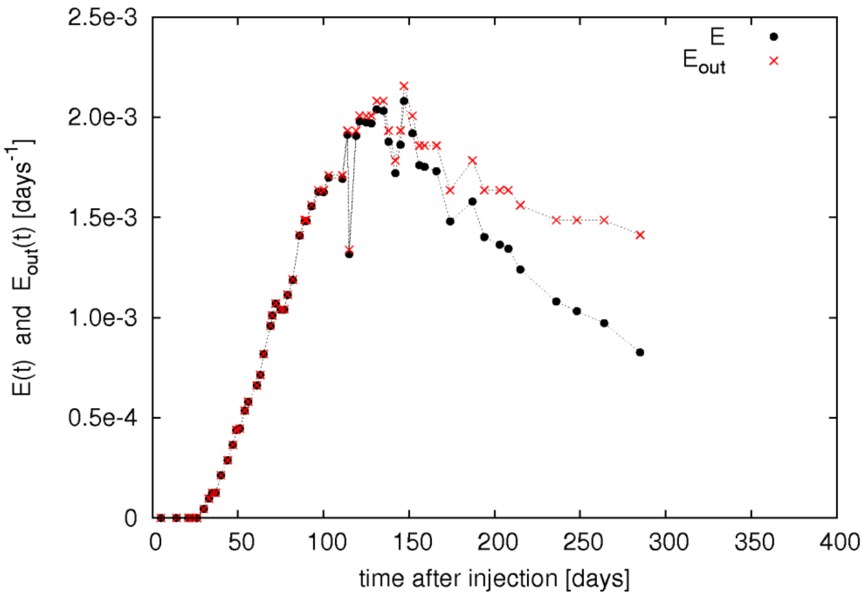
β = 0.6 gives match (So=0.24)

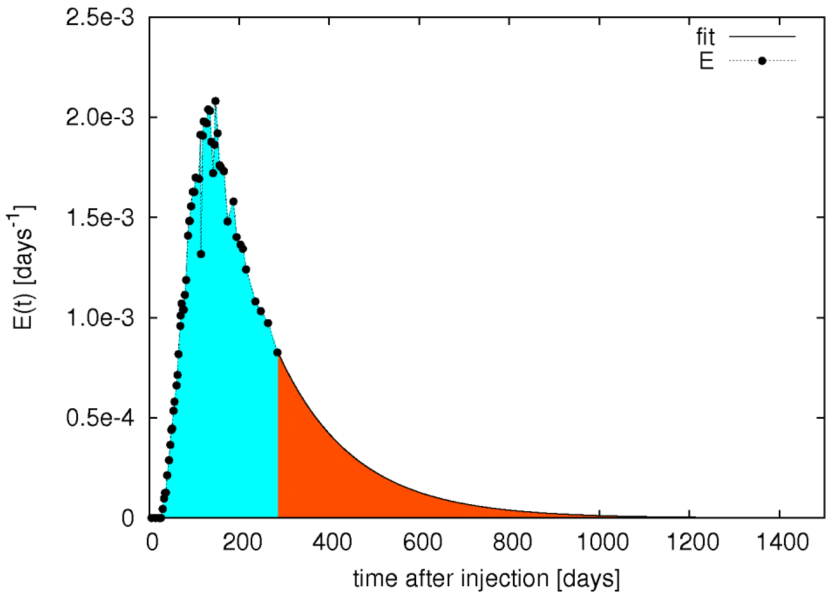


β=0.6, K=1.9 gives saturation: $So = \beta/(\beta + K) = 0.6/(0.6+1.9) = 0.24$

RTD analysis of PITTs

Must first correct for re-injection & extrapolate to infinity





LAV-1 results

Tracer	β	K	$\overline{S_o}$ [%]
IFE-WTP8	0.6	1.9	24
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

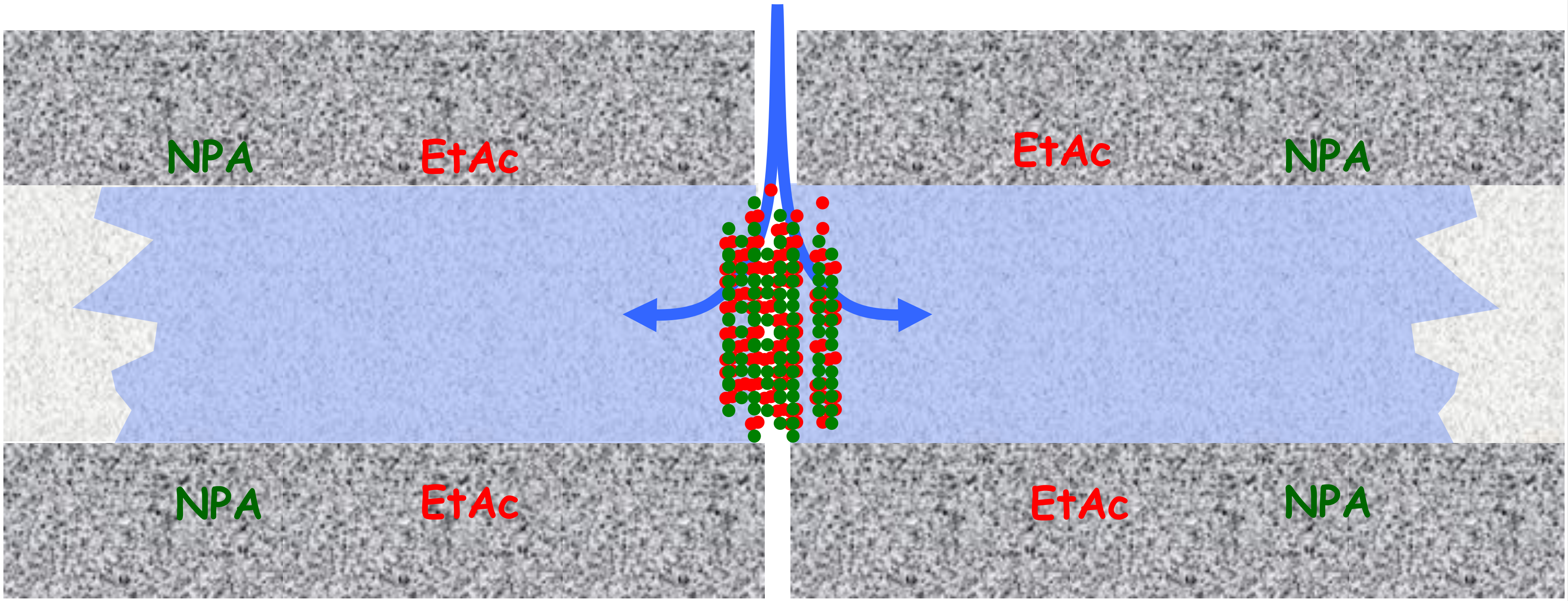
Results are consistent

LAV-2 results

Tracer	β	K	$\overline{S_o}$ [%]
IFE-WTP8	0.55	1.9	22
IFE-WTP7	0.65	2.4	21
IFE-WTP3	0.45	1.5	23
IFE-WTP2	0.45	1.5	23
IFE-WTP1	0.60	2.1	22
IFE-WTP4	0.70	2.9	19

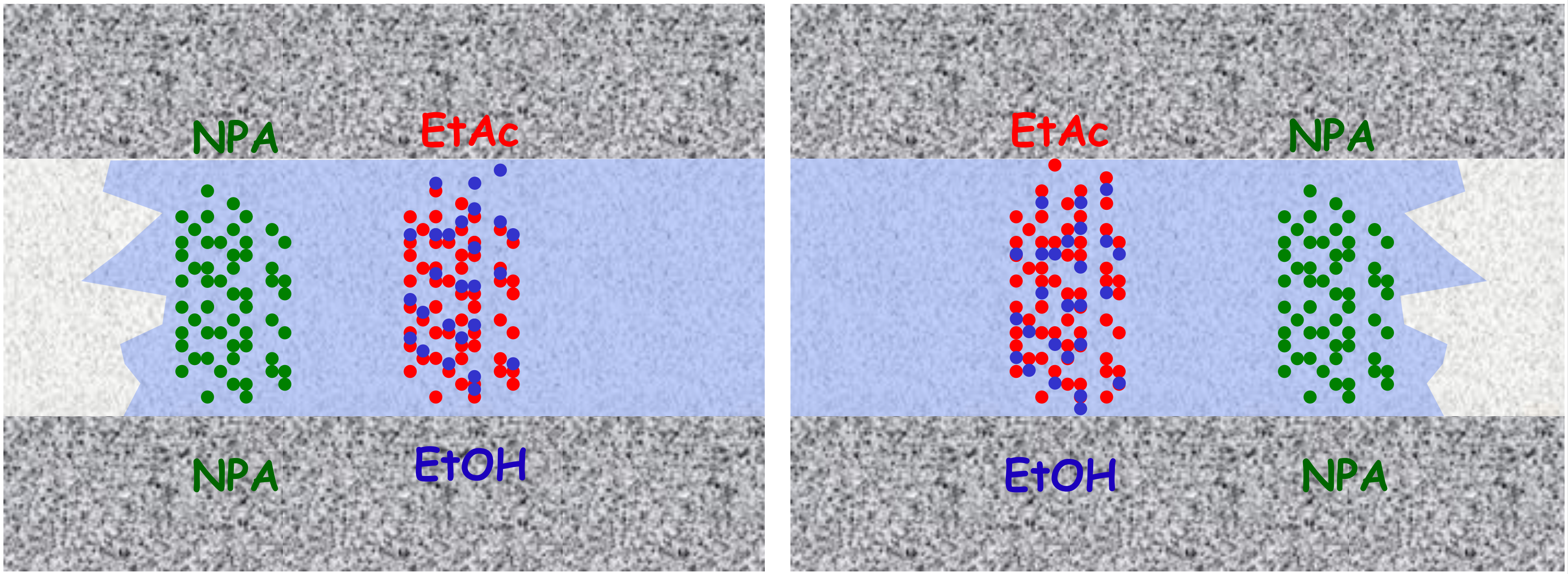
Results are consistent

SWCTT stage 1 injection



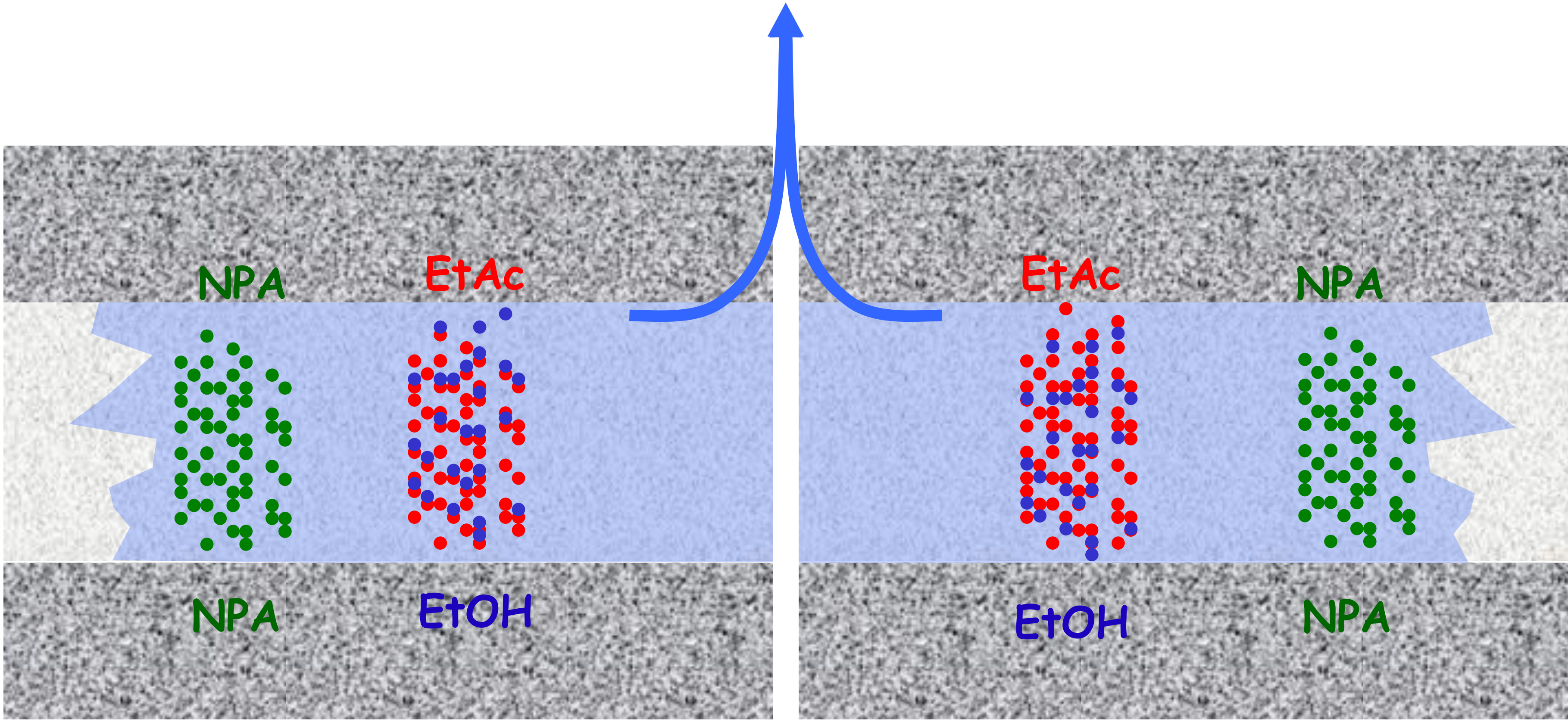
Water and ester is injected into watered out section

SWCTT stage 2 hydrolysis shut-in



Some of the ester hydrolyses to alcohol

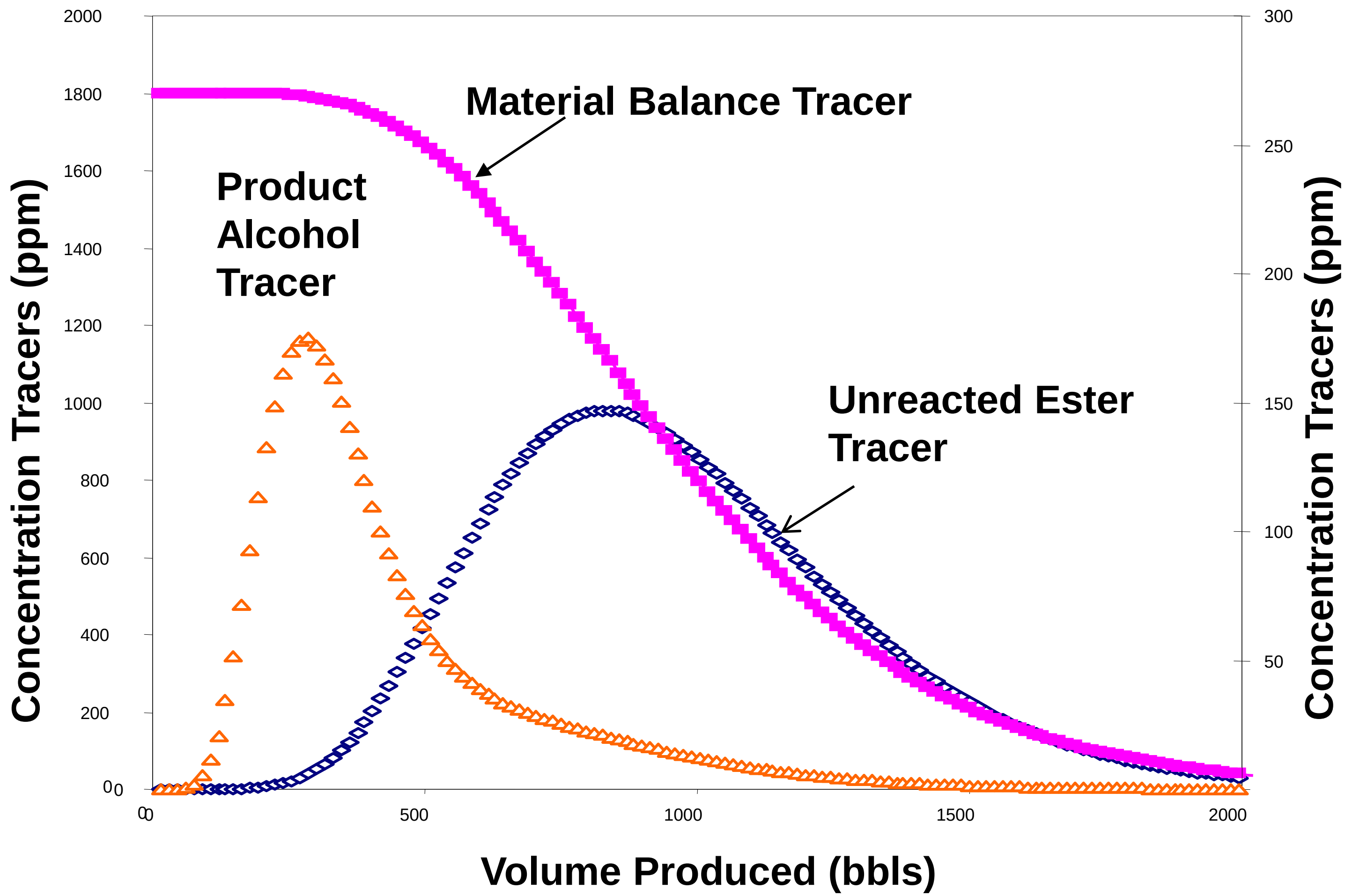
SWCTT stage 3 back production



The ester partition to oil and is delayed, compared to the alcohol

The water tracer is catching up on the partitioning tracer.

Single Well Chemical Tracer Test Production Curve



Partitioning interwell tracer test (PITT)

- Exploits the delay of partitioning tracers compared to non-partitioning tracers
- Works by injecting partitioning & non-partitioning tracer simultaneously
- Saturation can be estimated by:

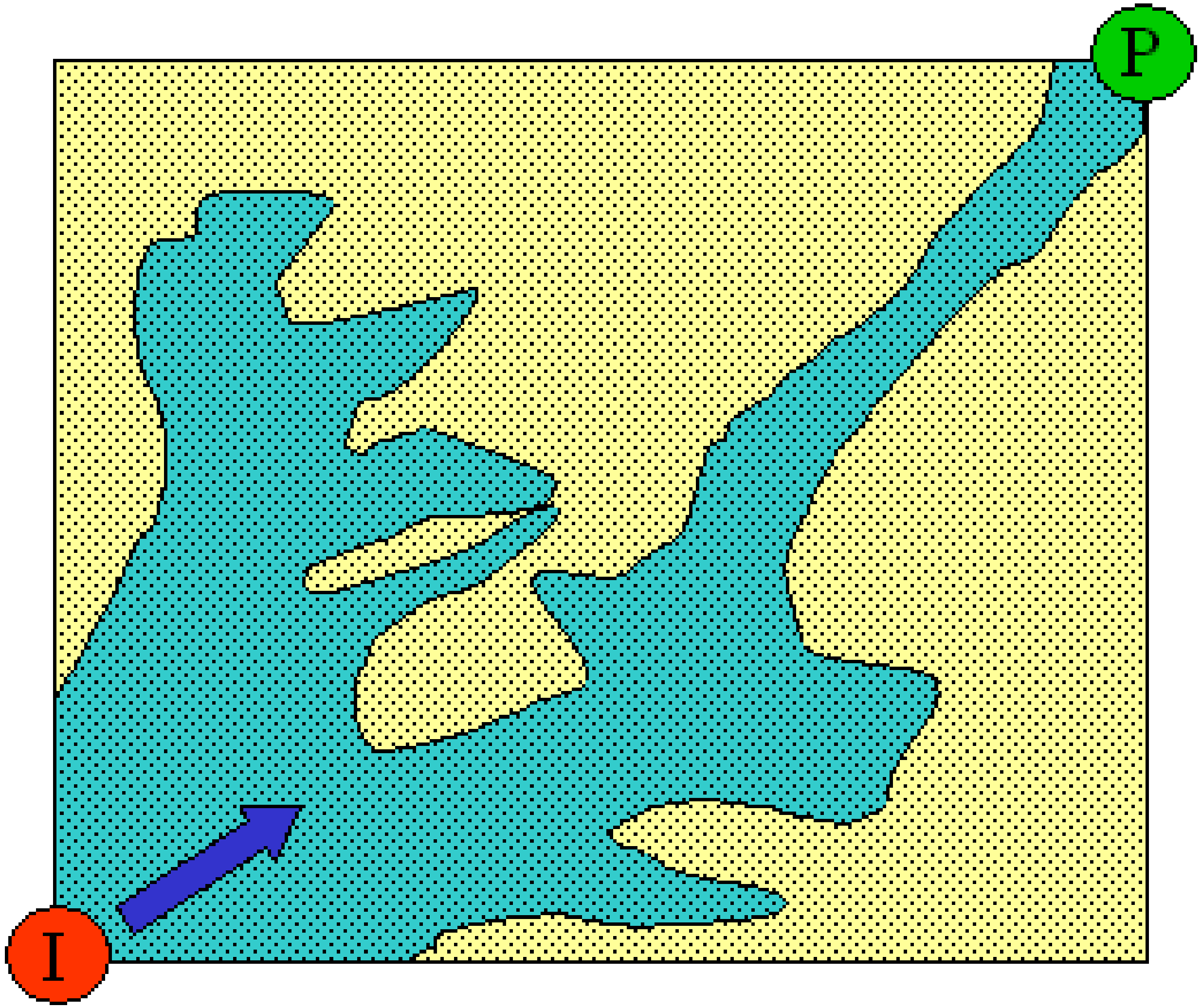
$$S_o = (T_p - T_i)/(T_p + T_i(K-1)) = \beta/(\beta + K)$$

where $T_p = T_i(1-\beta)$

EOR-methods

Enhanced oil recovery

CO_2–EOR challenges



Synthesis of ^{35}S-labeled surfactant

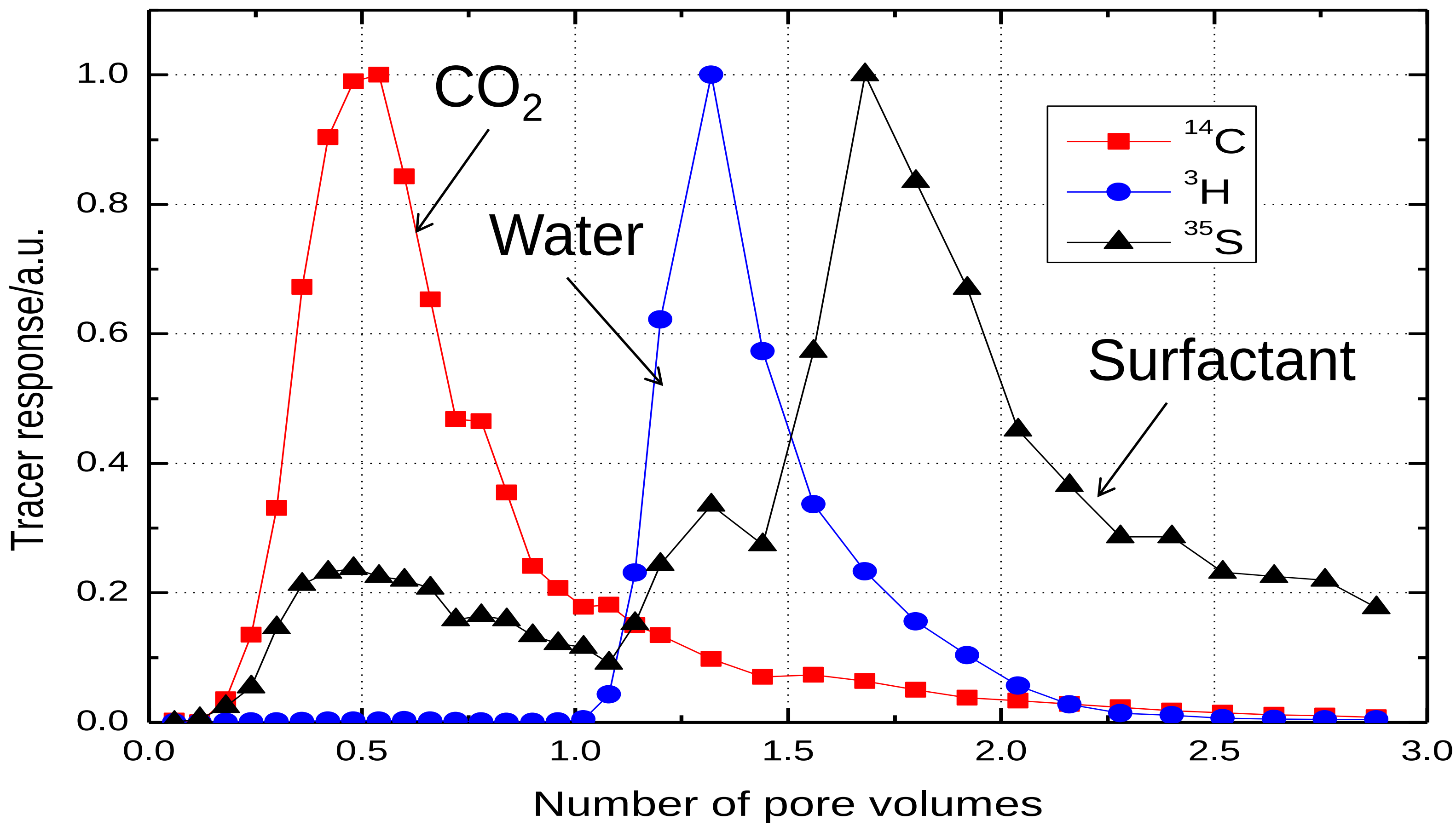
- **Synthesis of the sulfonation agent acetylsulfate:**

$$H_2{}^{35}SO_4 + CH_3\text{-COOOC-}CH_3 \rightarrow$$
$$CH_3\text{-COO}^{35}SO_3H + CH_3\text{-COOH}$$

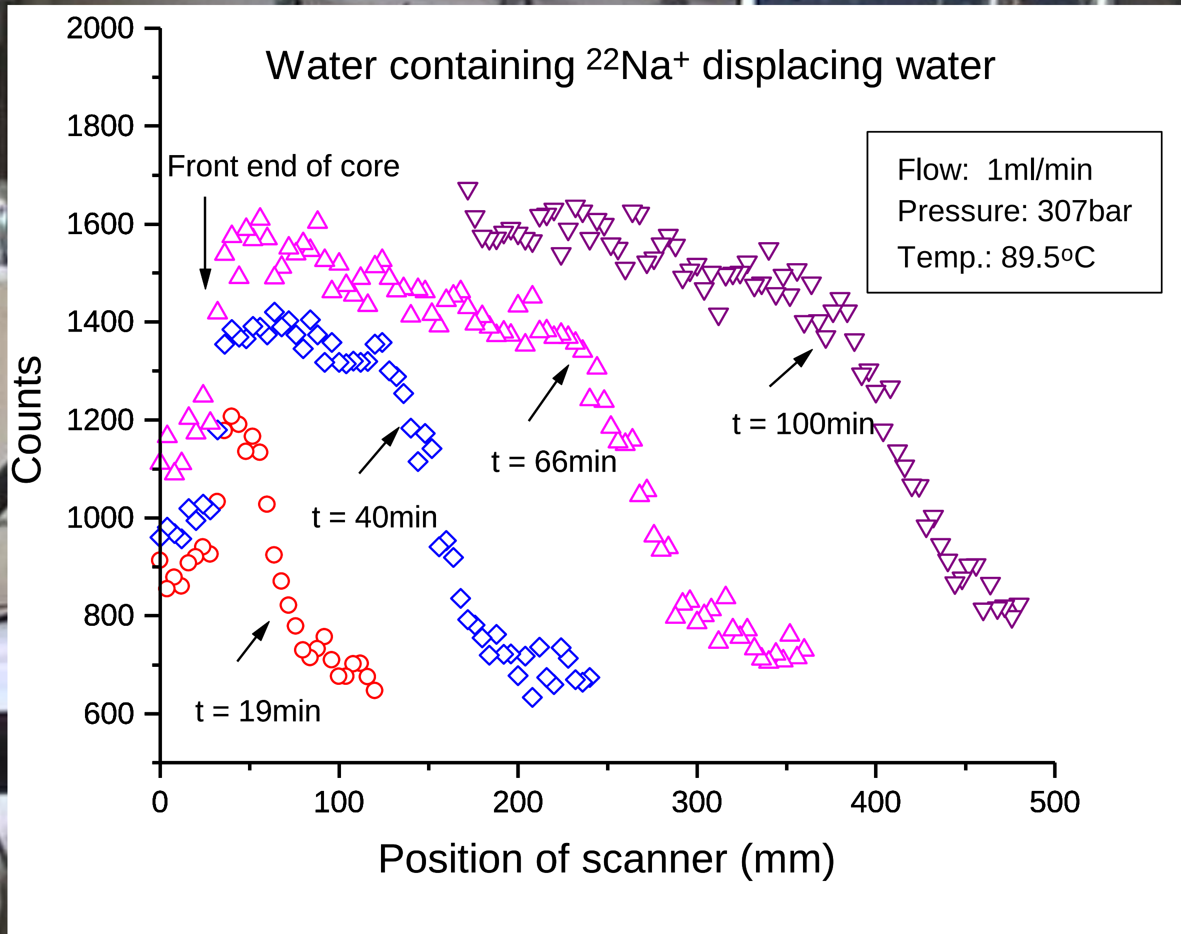
- **Sulfonation of 1-dodecene to get the surfactant:**

$$CH_3\text{-COO}^{35}SO_3H + R\text{-}CH_2\text{-CH=}CH_2 \rightarrow$$
$$R\text{-CH=CH-}CH_2\text{-}^{35}SO_3H + CH_3\text{-COOH}$$
$$(R = C_9H_{19})$$

Less liquid, more CO_2



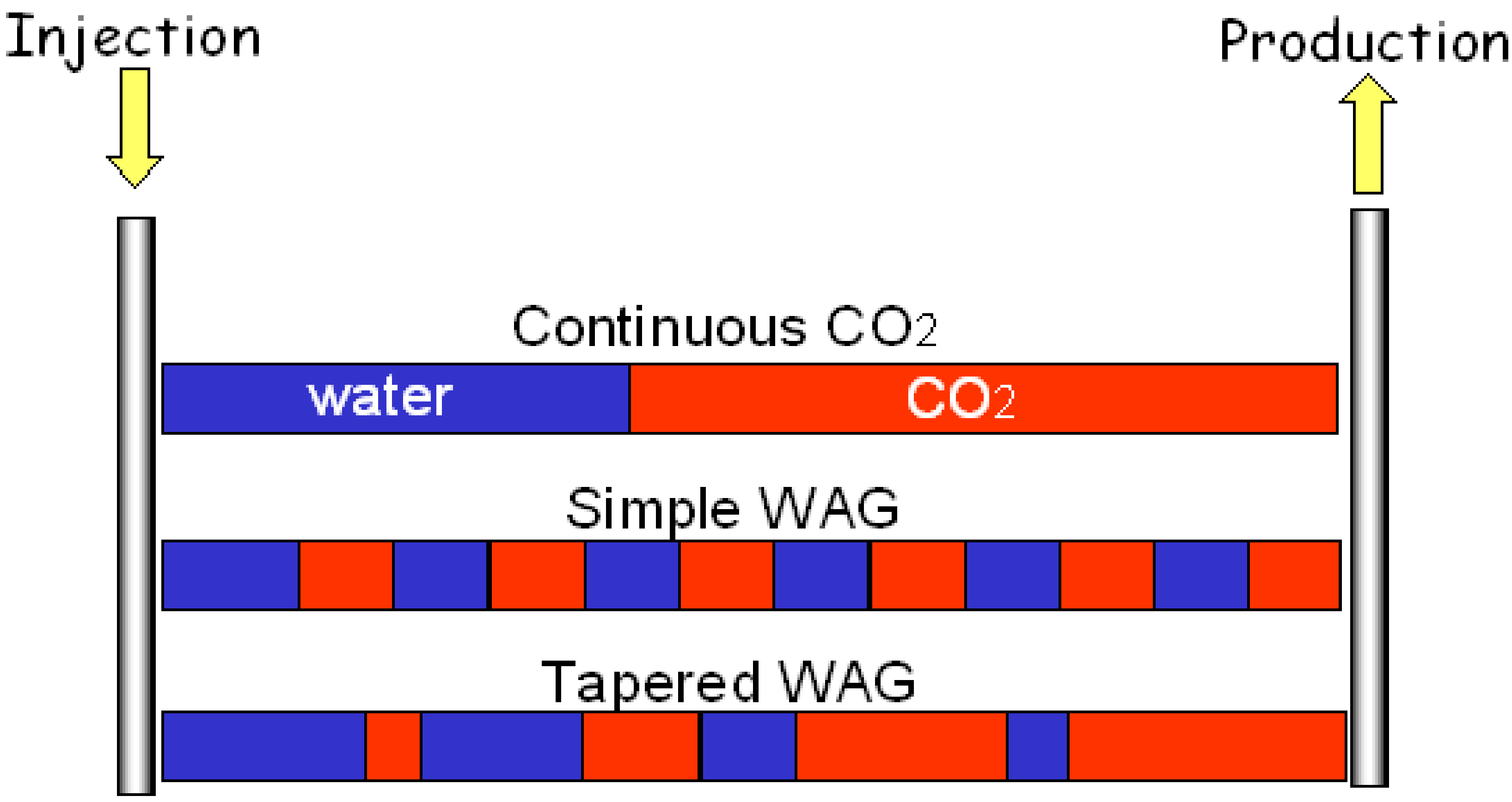
Using $^{22}Na^+$ tracer to monitor water front



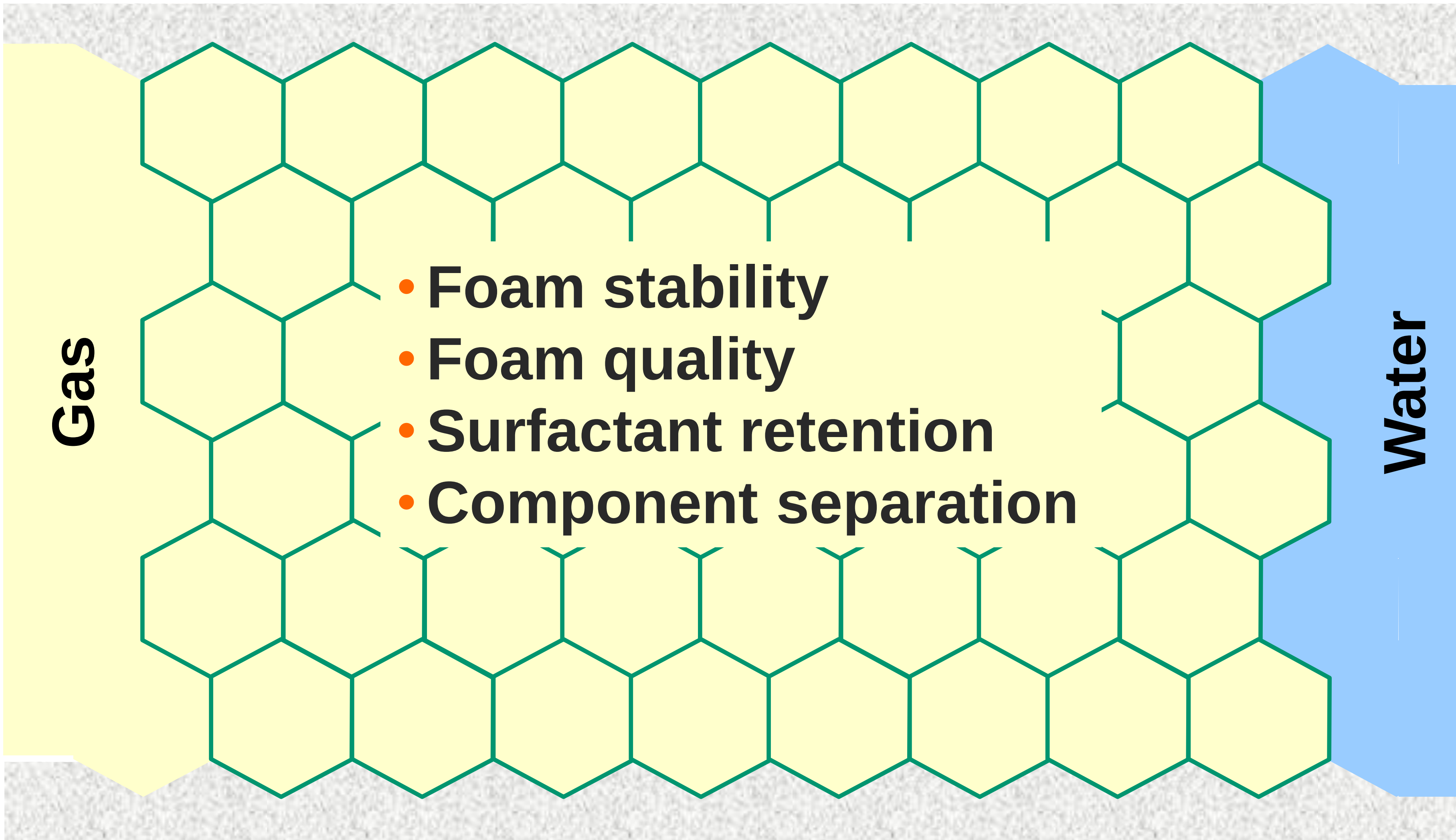
How can CO_2 sweep efficiency be improved ?

- CO_2/foam: What kind of surfactant?
- Increasing viscosity by polymers: What kind of polymer?
- WAG: How long (frequency of) slugs?
- What are the displacement mechanisms with supercritical or dense-phase CO_2?

What injection strategy to follow?



CO_2 foam flooding: Parameters

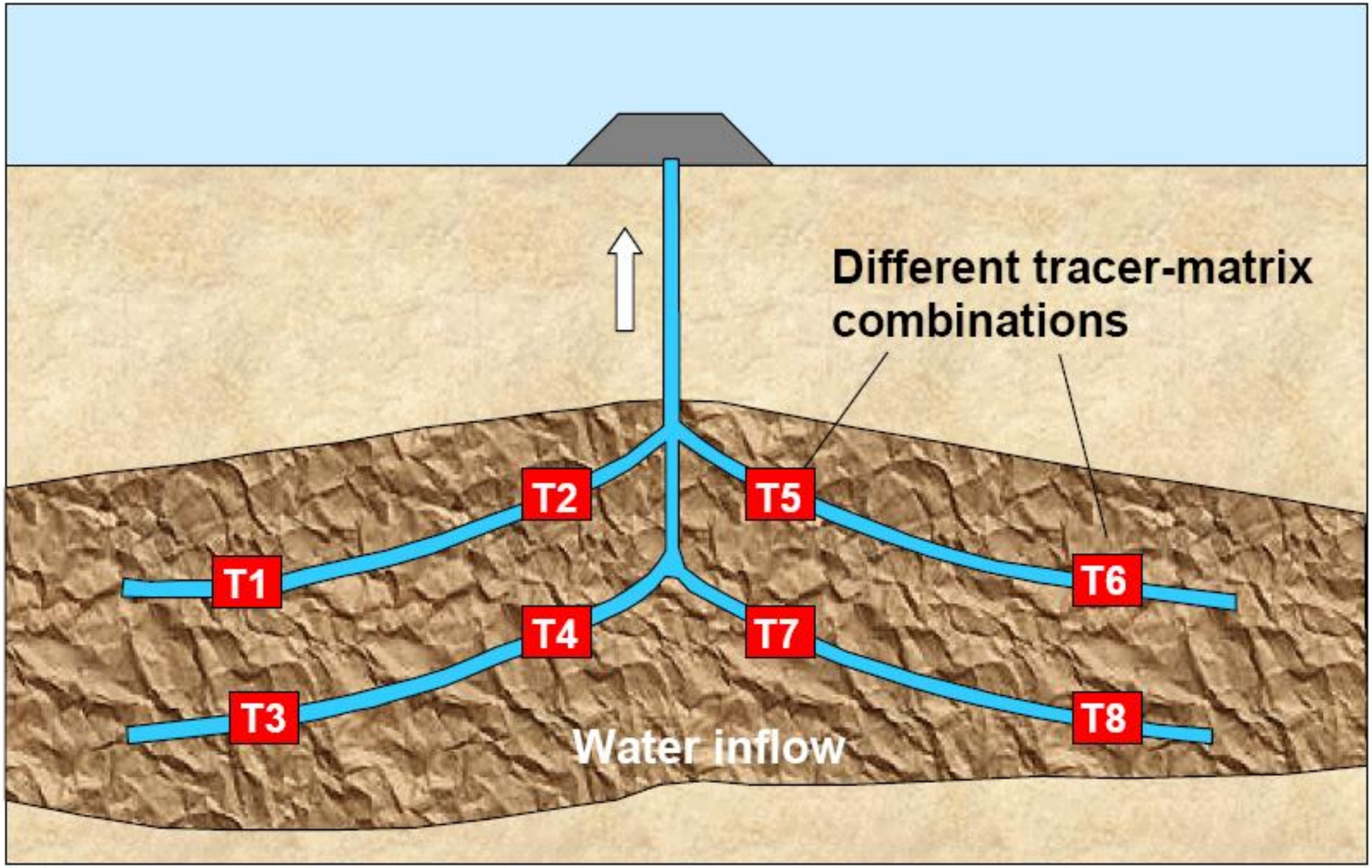


- Foam stability
- Foam quality
- Surfactant retention
- Component separation

Production and flow assurance

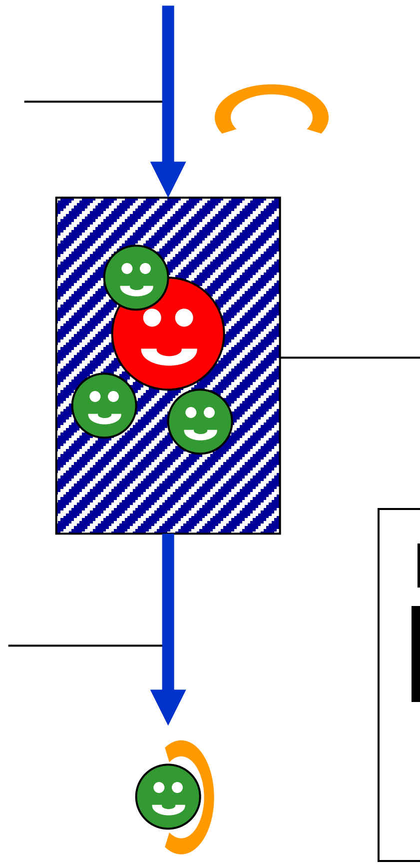
Well inflow monitoring

Complex well inflow monitoring



Generator principles (2)

Aqueous solution (complexing agent, salinity, pH)



Mother nuclide

Aqueous solution + complexed daughter possibly extractable into organics

↓

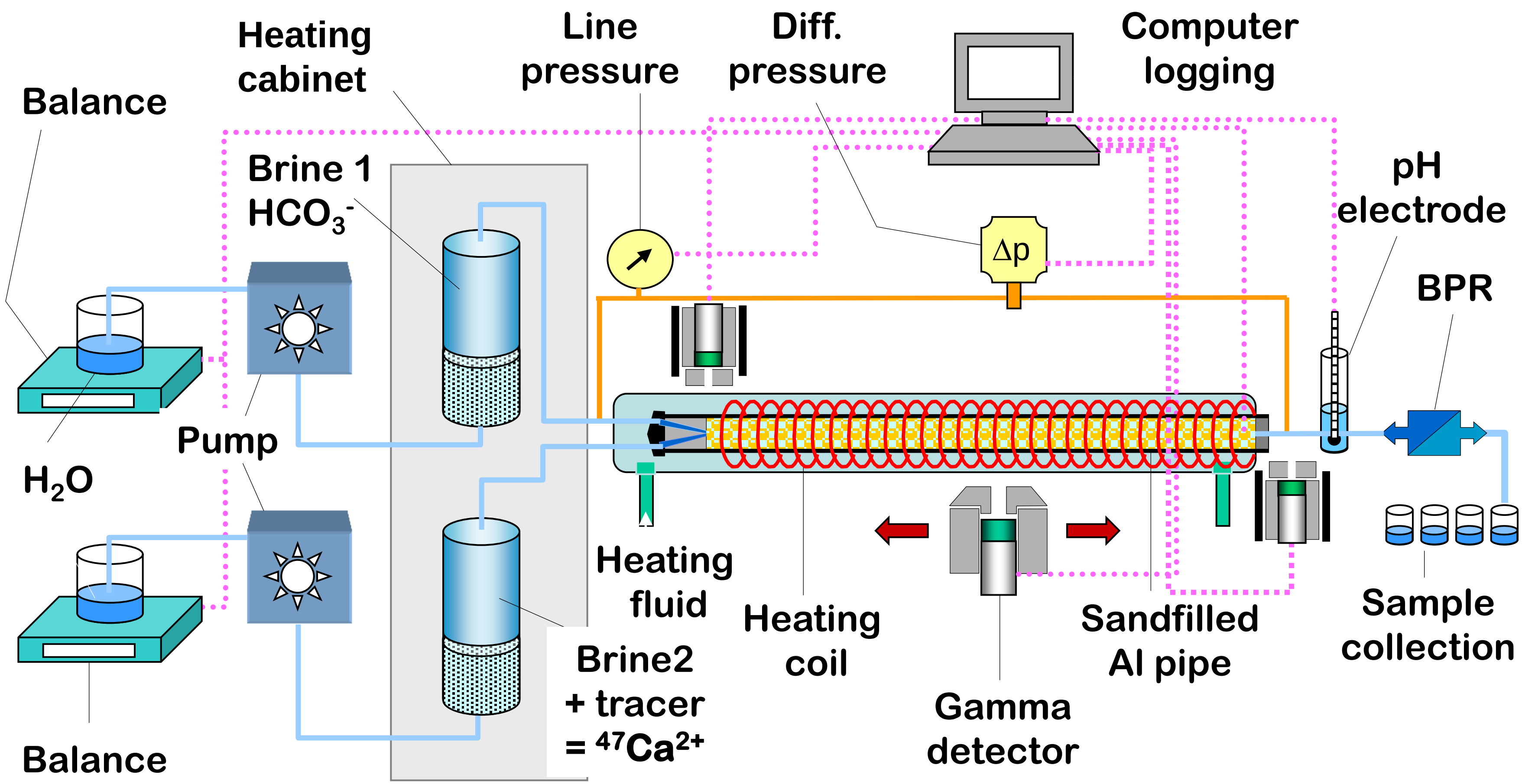
Aqueous or organic tracer

Example:

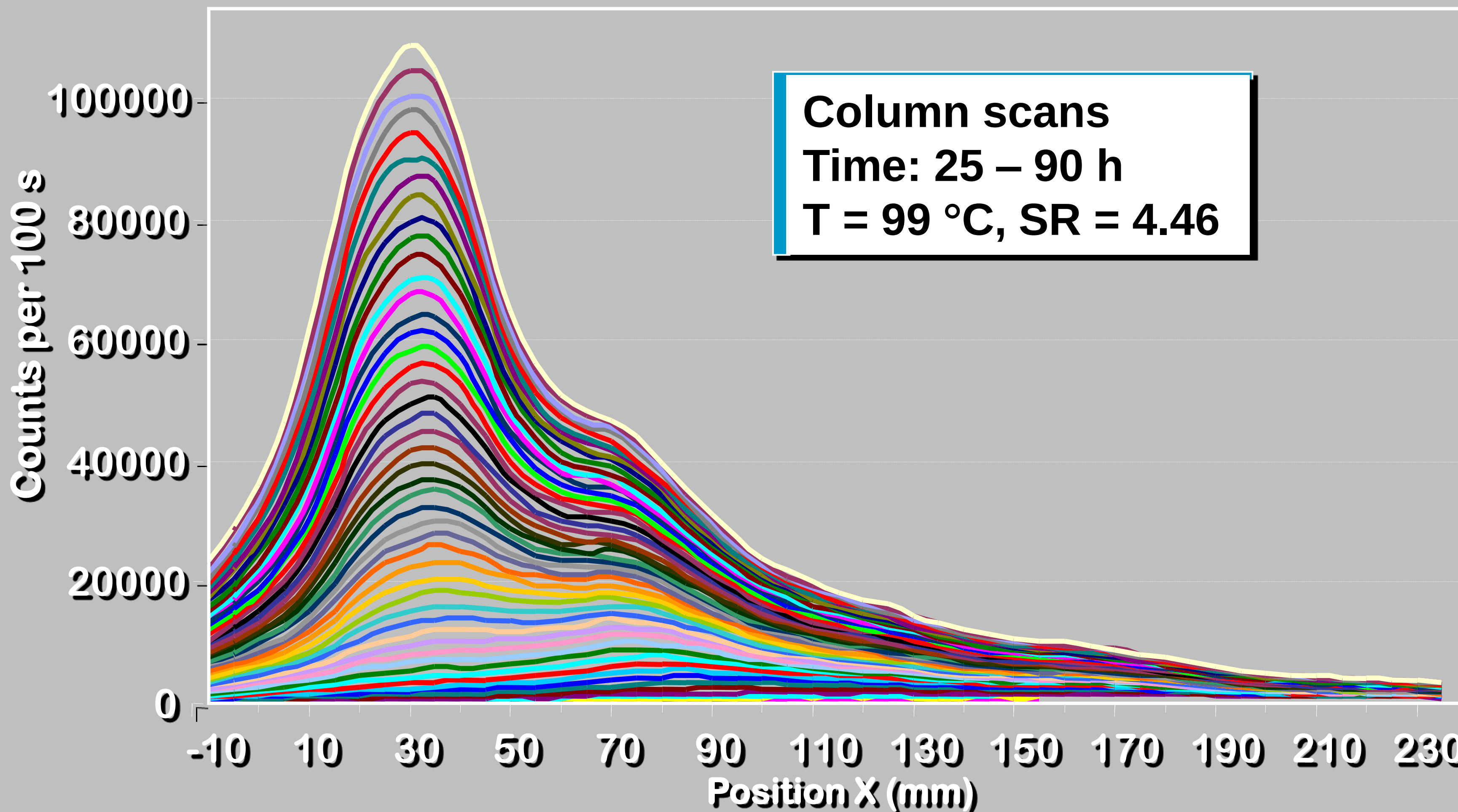
$^{52}Fe \rightarrow {}^{52m}Mn$

Anion exch.column, elution with tartrate

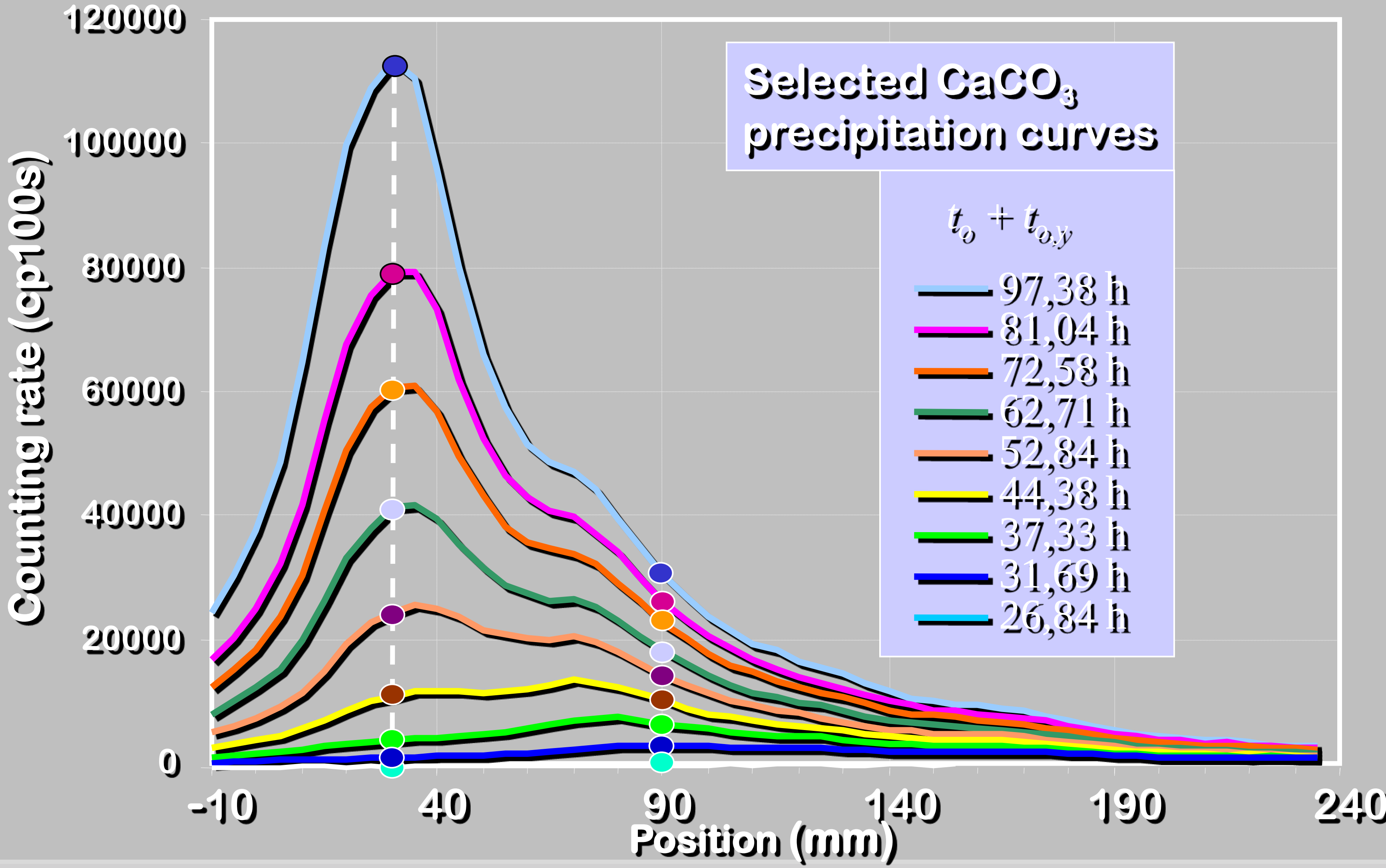
Experimental setup measurements of scaling kinetics



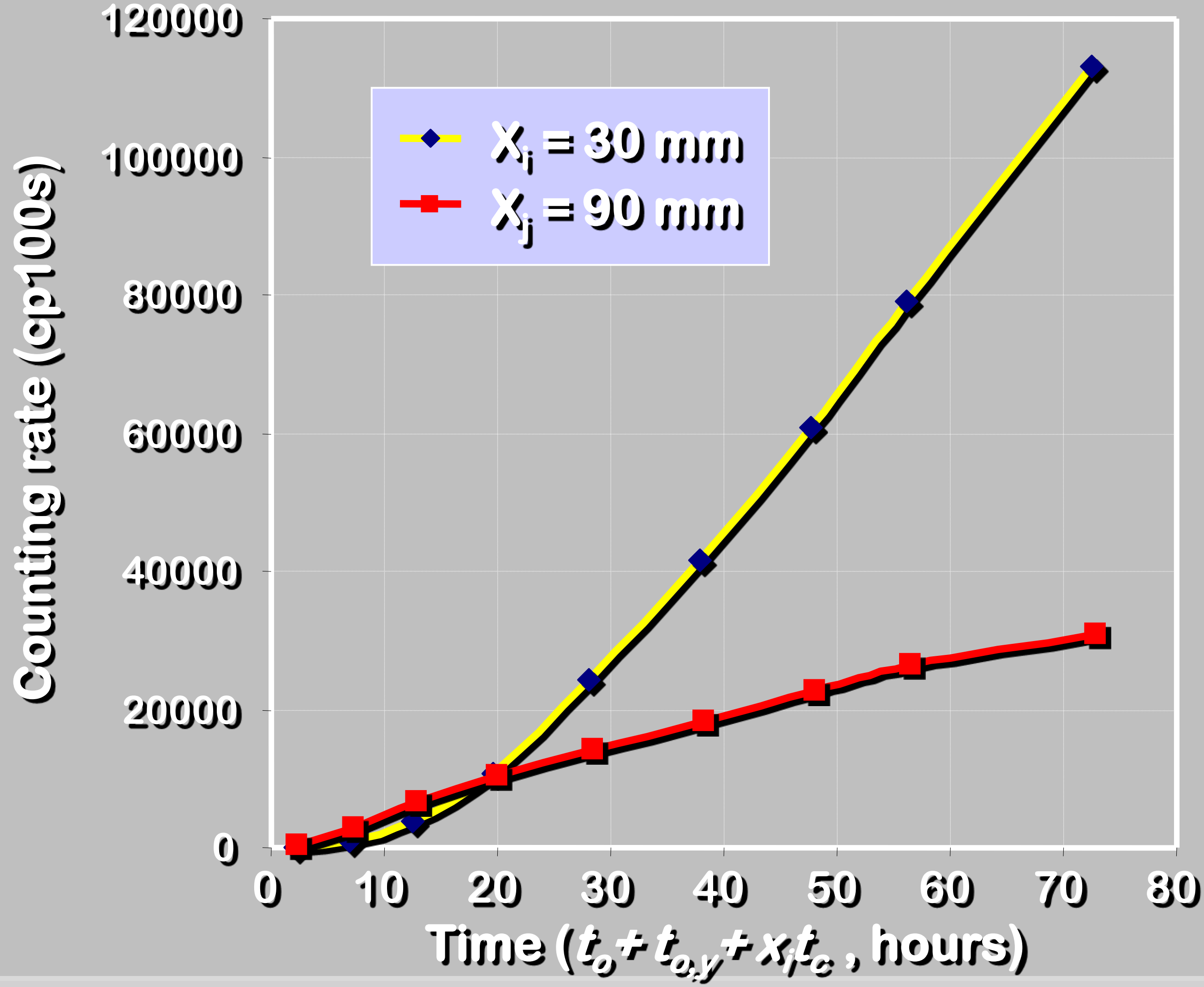
Column scans



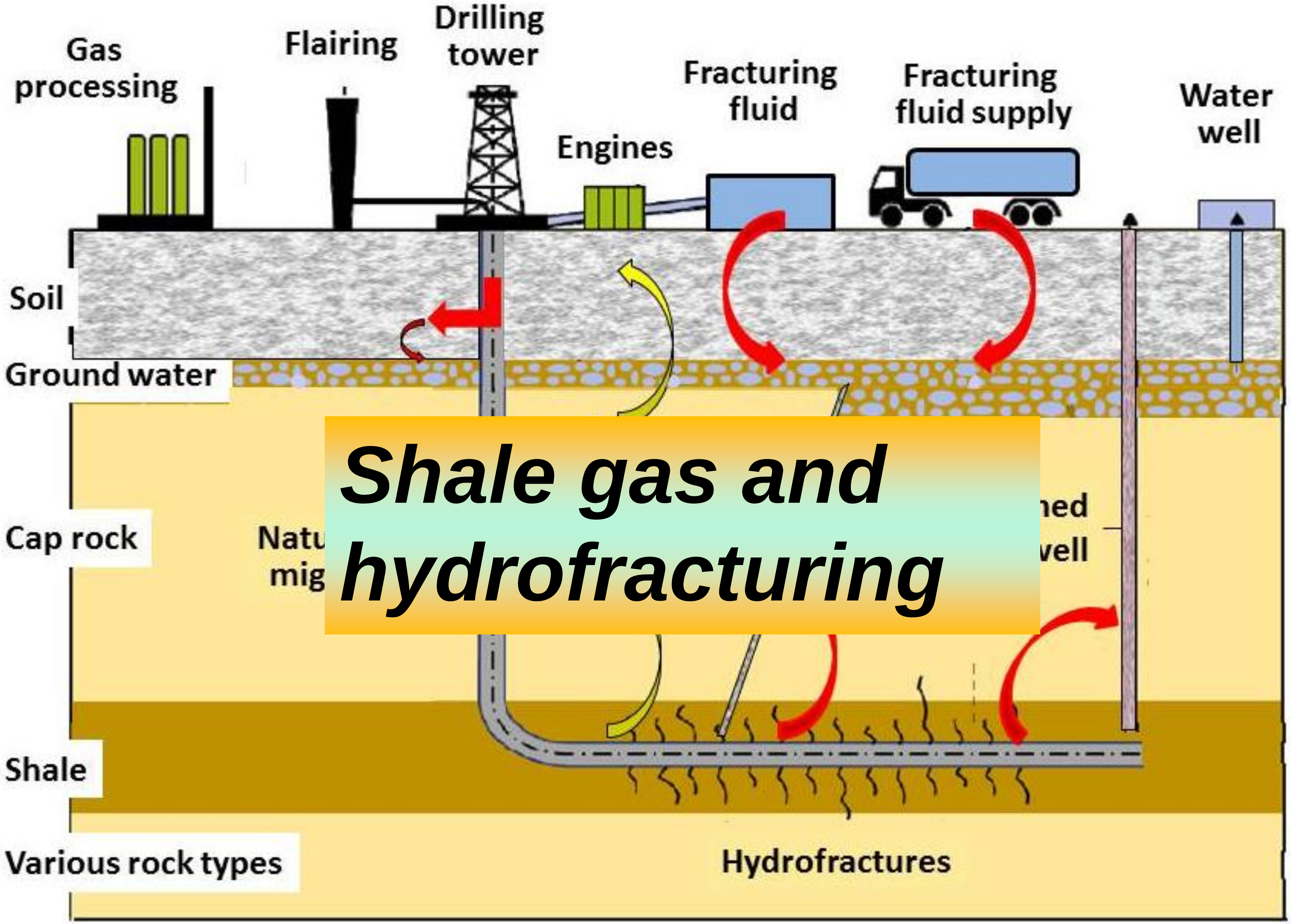
Selected column scans



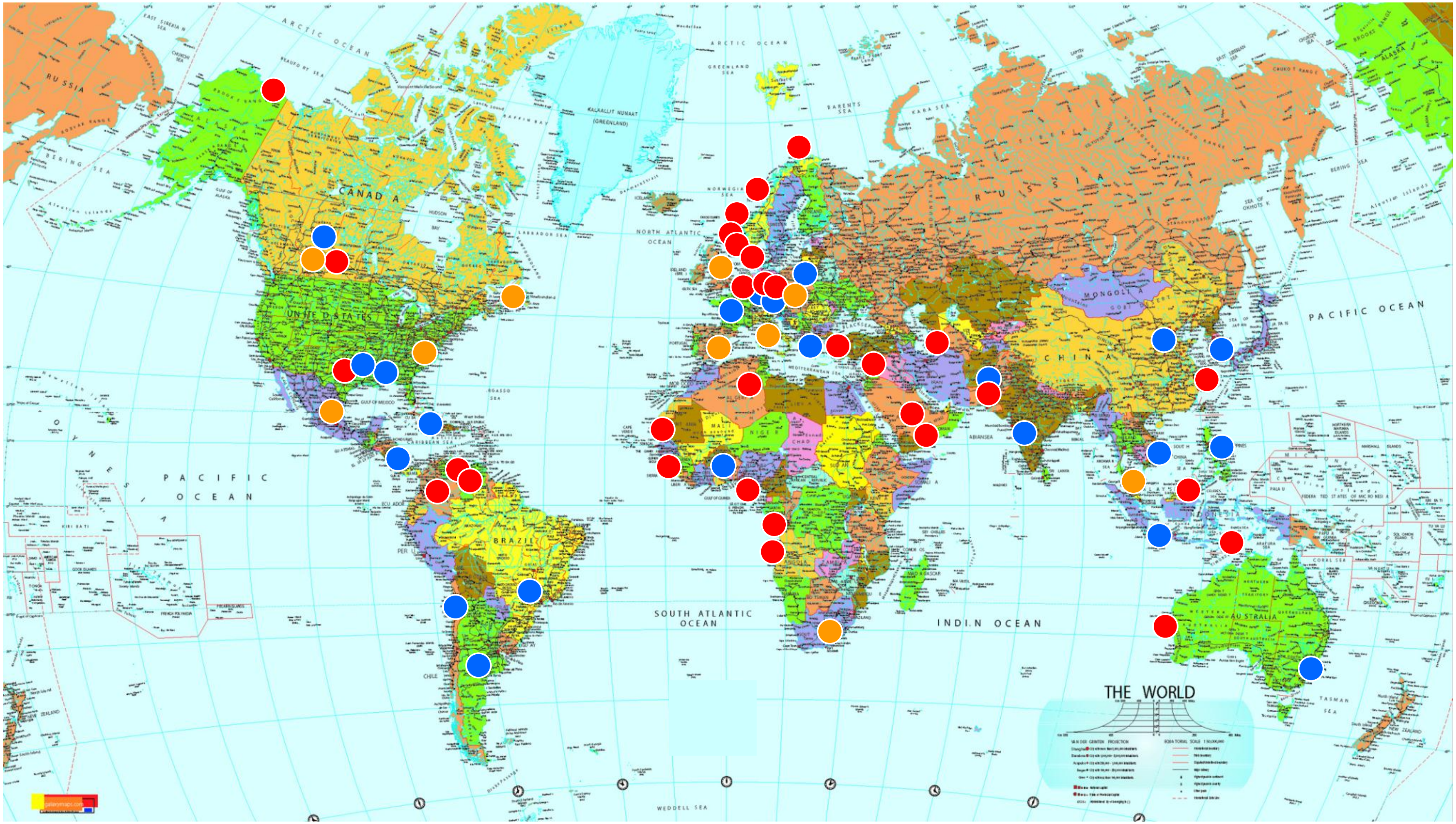
True scaling rates at x_i and x_j



Shale gas and hydrofracturing

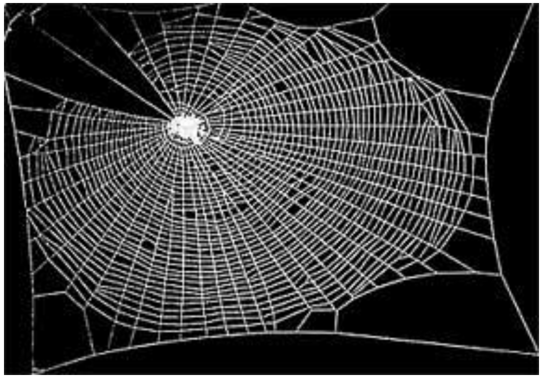


Tracer projects and contacts world-wide

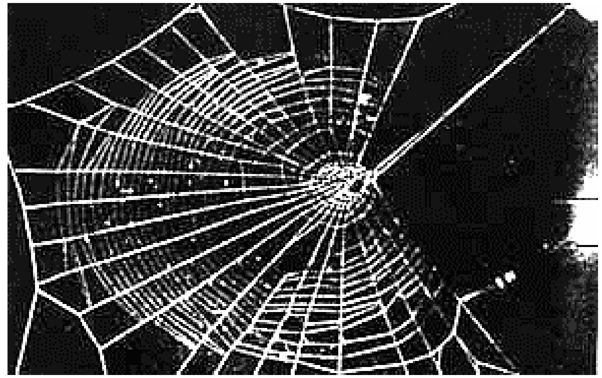


● Field experience ● Common R&D projects ● Technology contacts

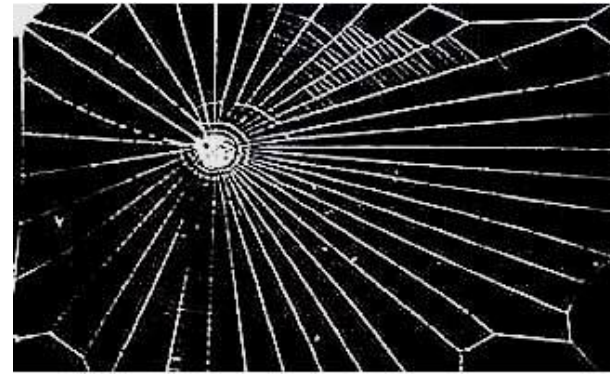
Warning: Spider on drugs



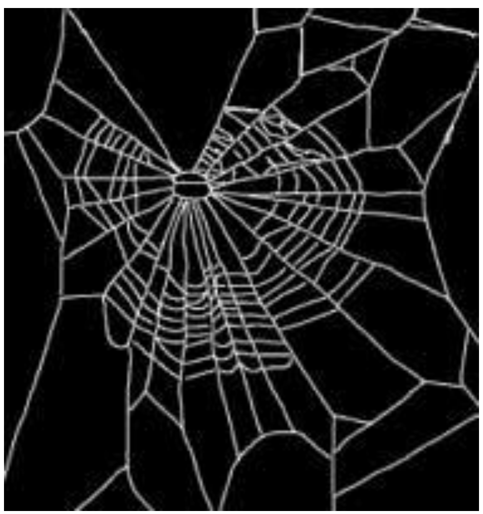
Drug Free Spider



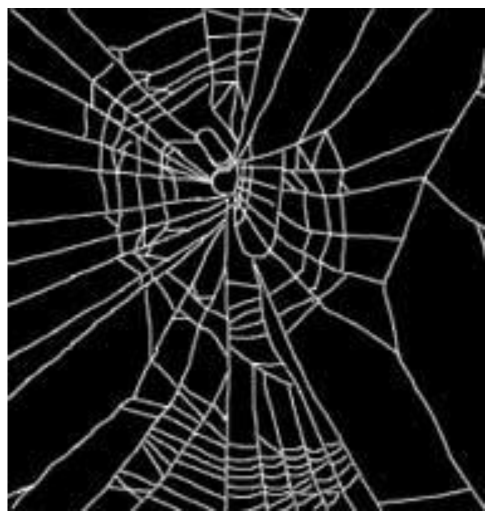
Exposed to mescaline\Peyote



Exposed to LSD



Exposed to Marijuana



Exposed to Benzedrine/ Speed

Exposed to Caffeine