CO_2 for Methane Production from Hydrate Reservoirs

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NewScientist

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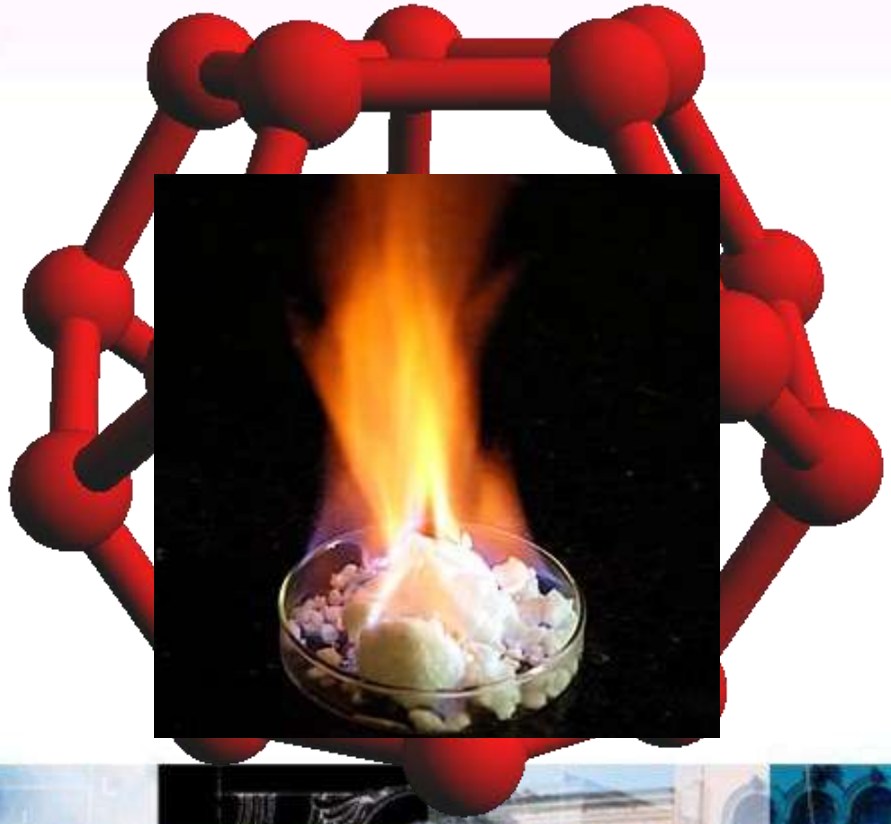
LAST CHANCE TO WIN! A piece of the moon

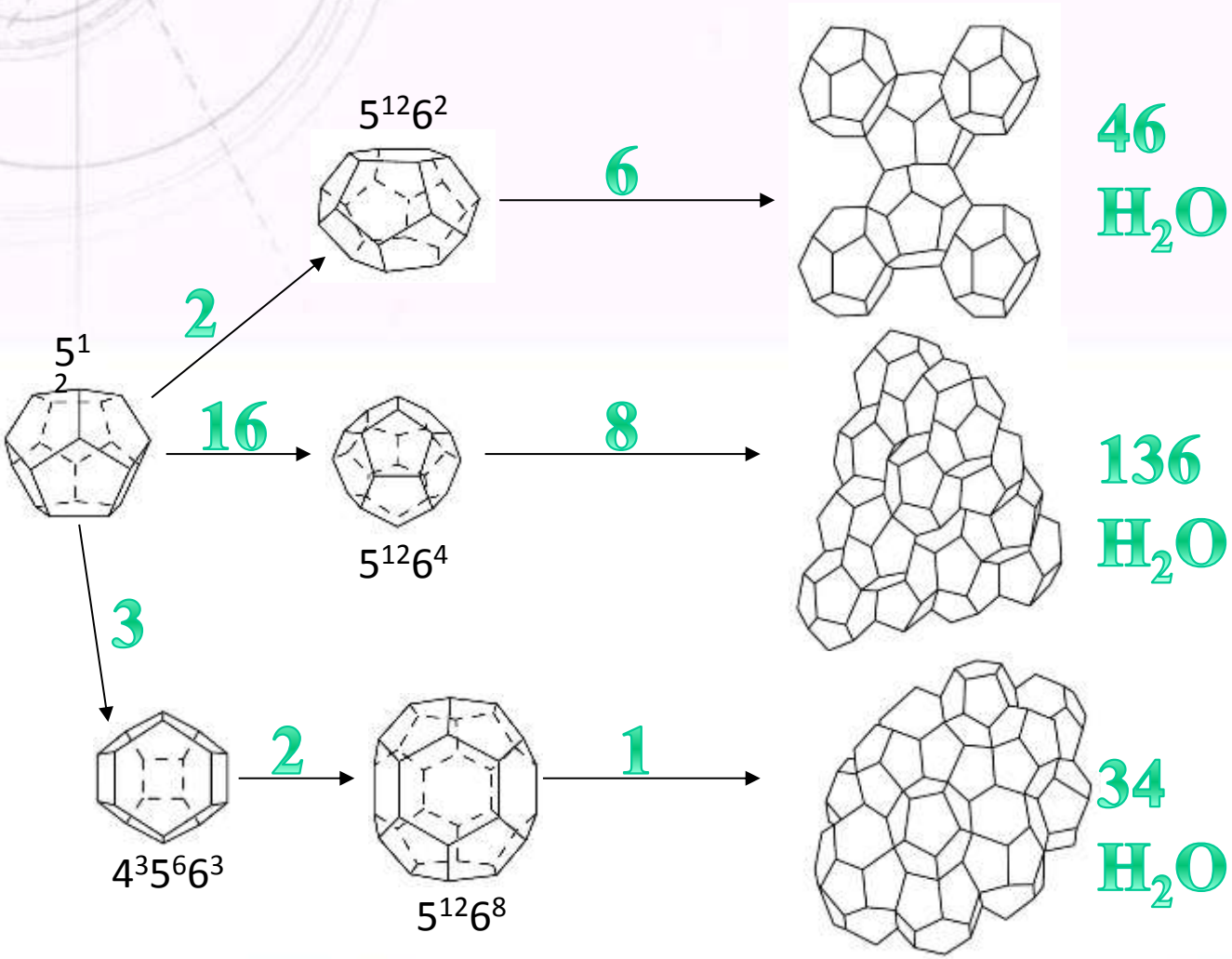
THE NEXT FOSSIL FUEL

A surprise successor to oil and gas

- Water molecule cages encapsulating a foreign molecules (e.g. methane)



HYDRATE STRUCTURES



Structure I

Methane, ethane,
Carbon Dioxide…

Structure II

Propane,
iso-butane…

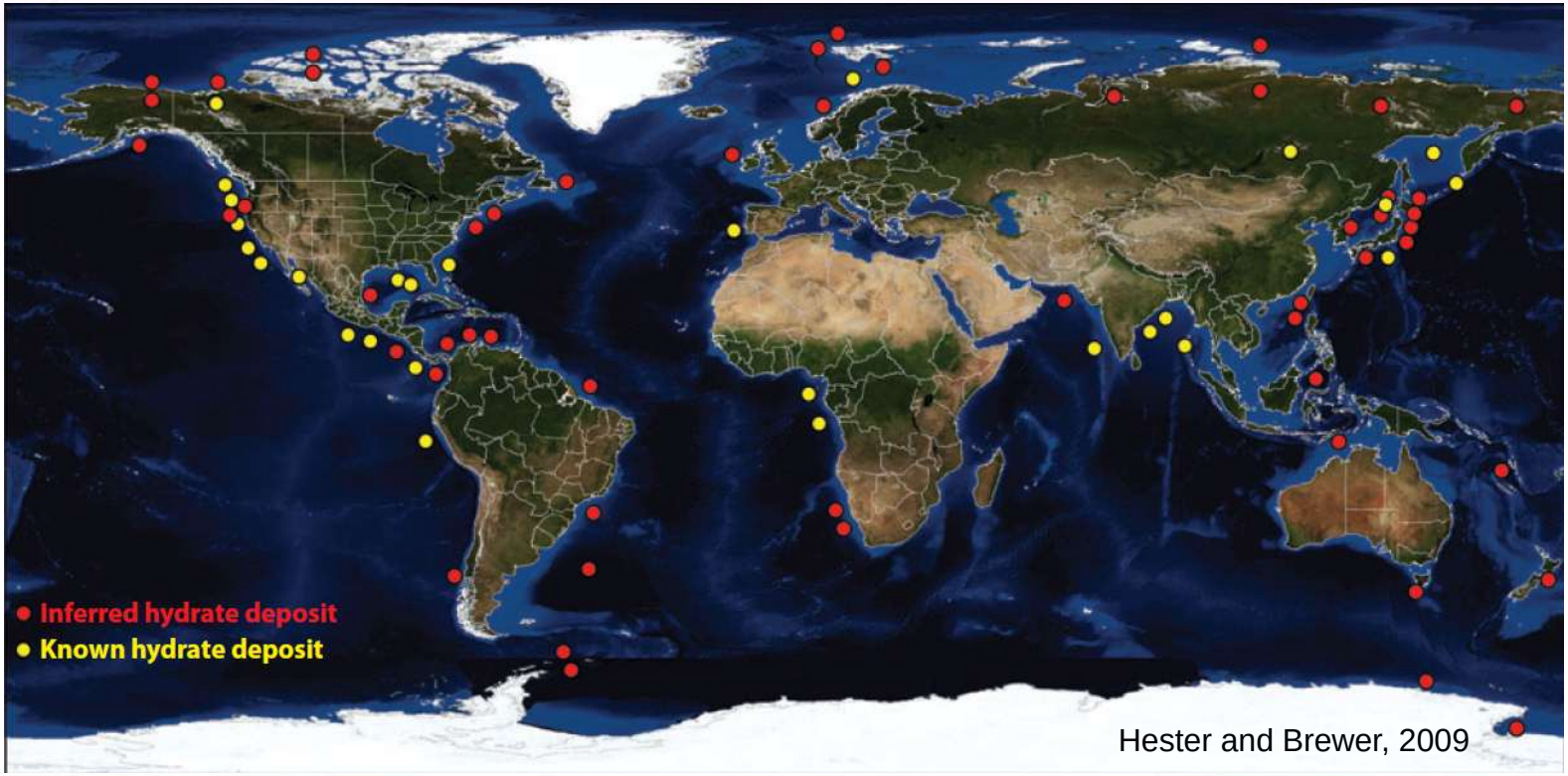
Structure H

Methane + neohexane,

Methane + cycloheptane

Renewed interest

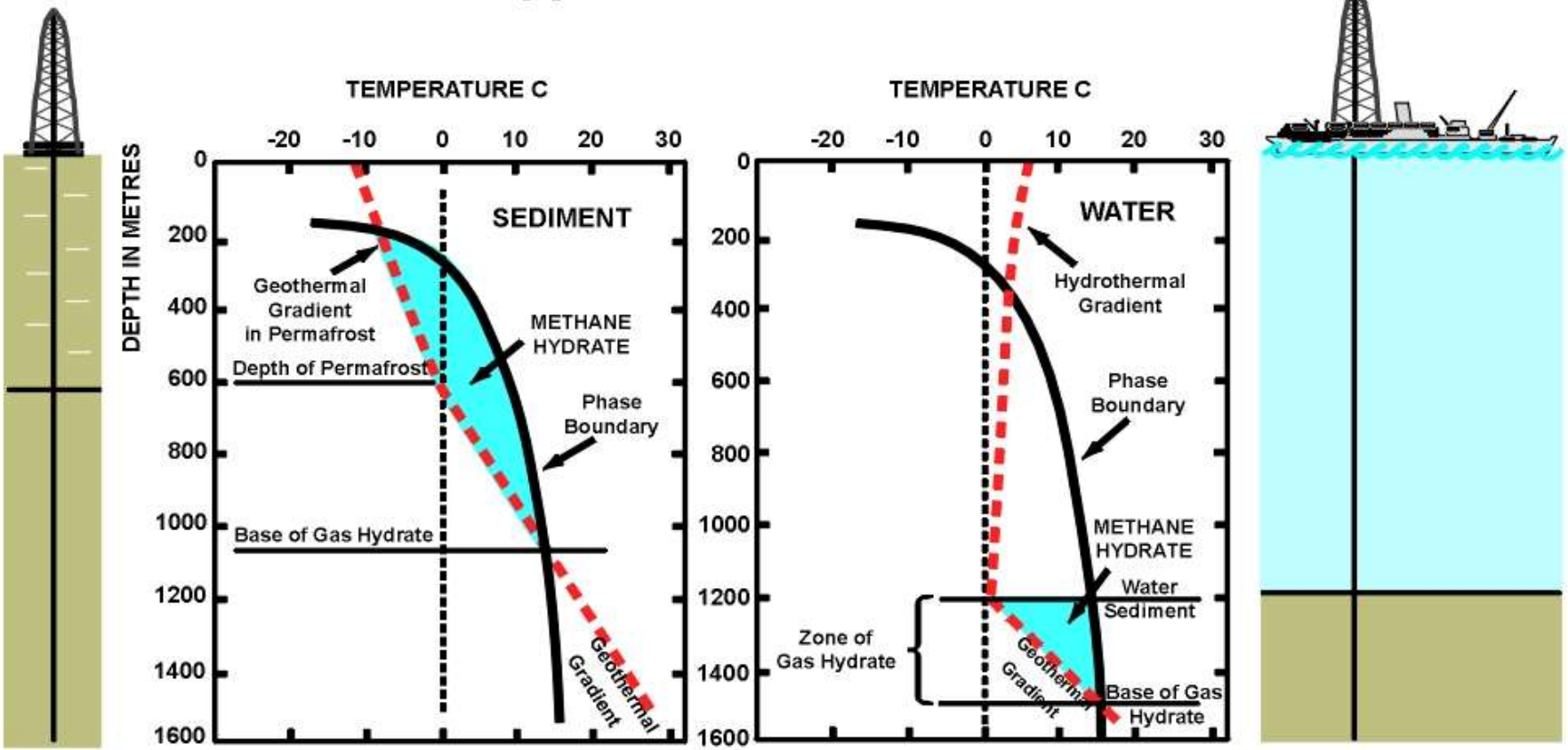
- Significant amount of energy
  - Permafrost regions
  - Marine environments (high water column)

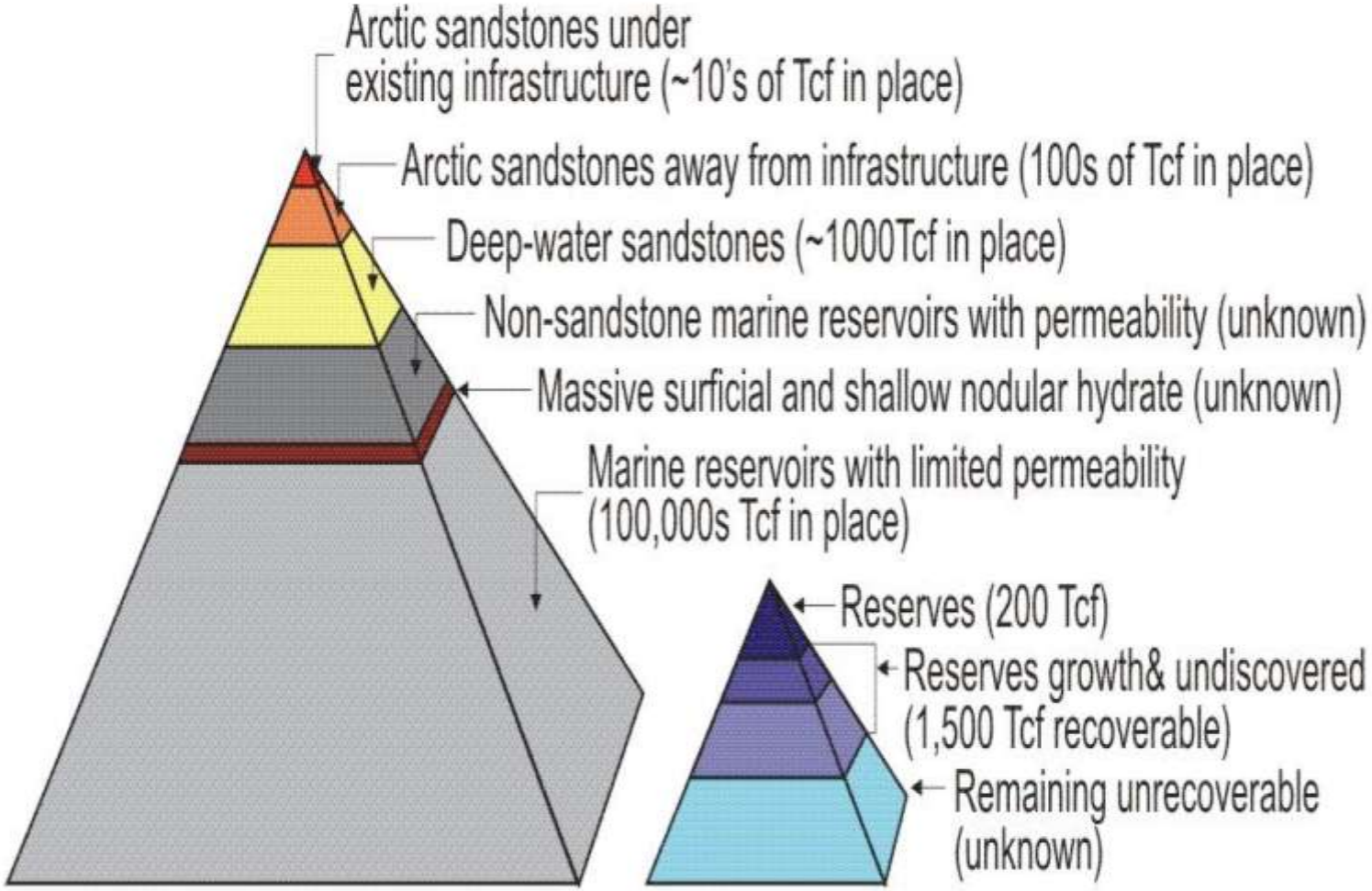


Hester and Brewer, 2009


2002/2008
2011-
Prudhoe Bay Unit L-pad
2013 offshore Japan

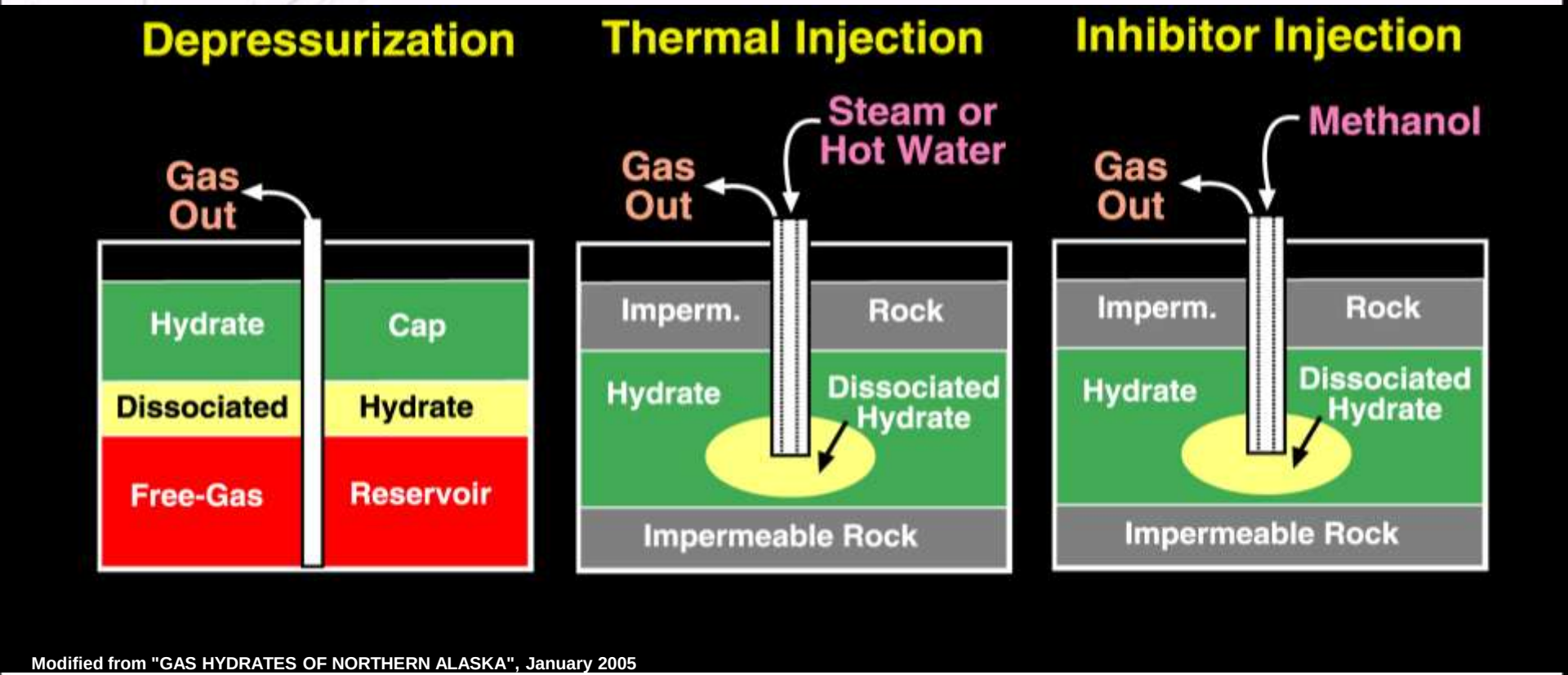
Gas Hydrate Stability





Gas Hydrates Resource Pyramid (left). To the right is an example gas resources pyramid for all non-gas-hydrate resources (Boswell, 2006).

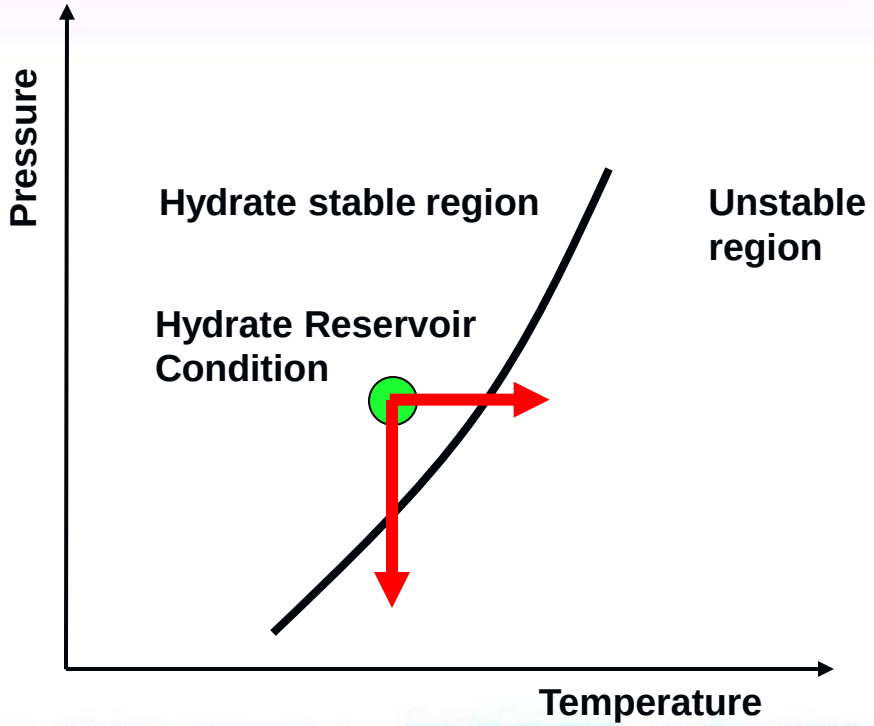
Gas Hydrate Production Methods



Modified from "GAS HYDRATES OF NORTHERN ALASKA", January 2005

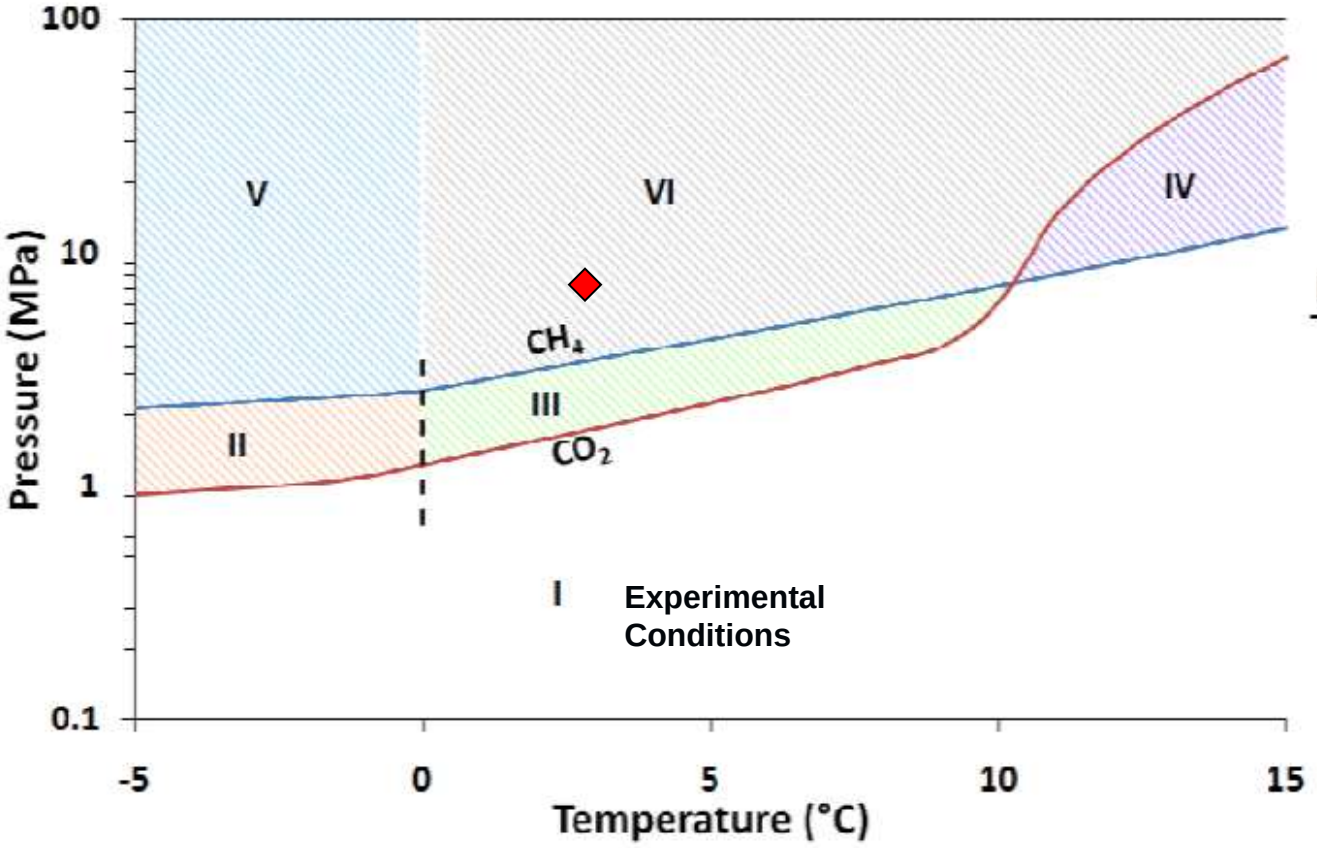
GAS HYDRATE PRODUCTION METHODS

- **Move the gas hydrate outside its stability region**
  - **Depressurization**
  - **Thermal stimulation**
  - **Hydrate inhibitors**
- **CO2 exchange**



CO2 Exchange - Project Motivation

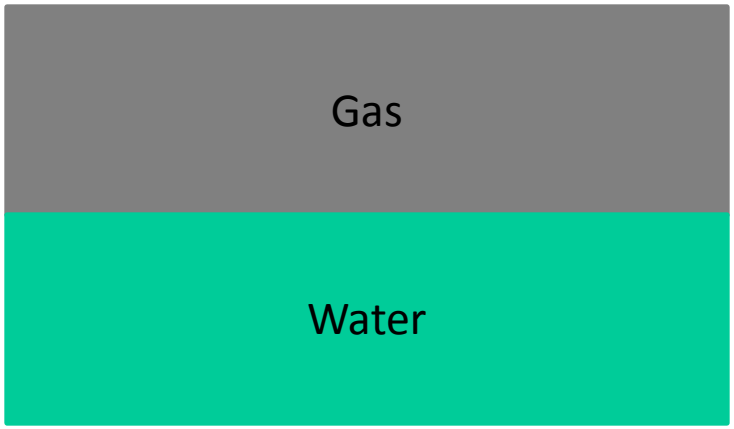
- **Methane production**
- **Simultaneous CO_2 Sequestration**
- **Spontaneous process**
- **No associated water production**
- **Formation integrity**



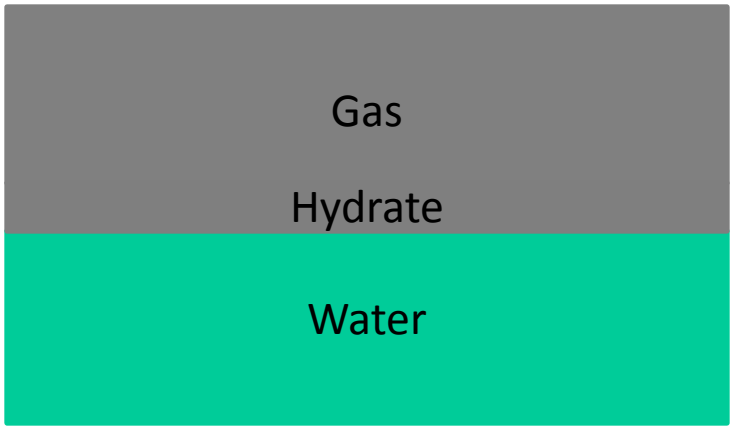
PT-Area	Water and Hydrate Phases
I	No hydrates
II	$I\text{-}H_{CO2}$
III	$L_W\text{-}H_{CO2}$
IV	$L_W\text{-}H_{CH4}$
V	$I\text{-}H_{CO2}\text{-}H_{CH4}$
VI	$L_W\text{-}H_{CO2}\text{-}H_{CH4}$

HYDRATE FORMATION

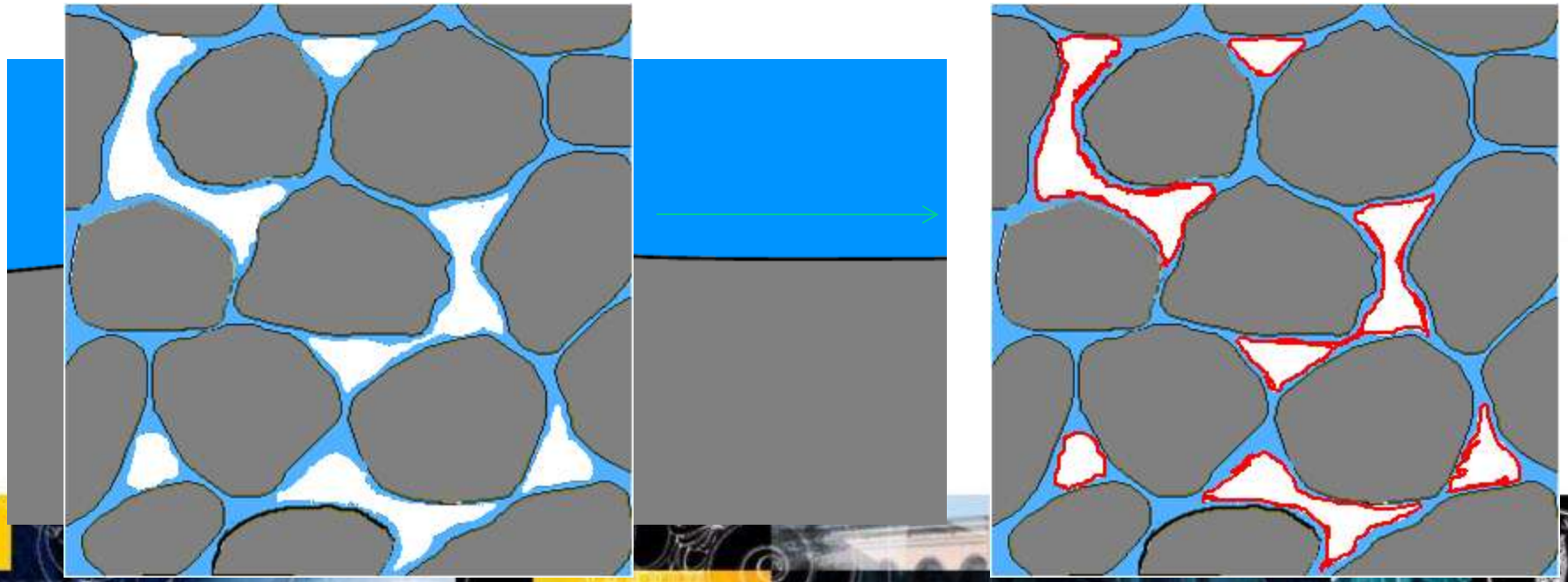
Atmospheric conditions



Hydrate stable conditions



CONDITIONS OF A HYDRATE RESERVOIR



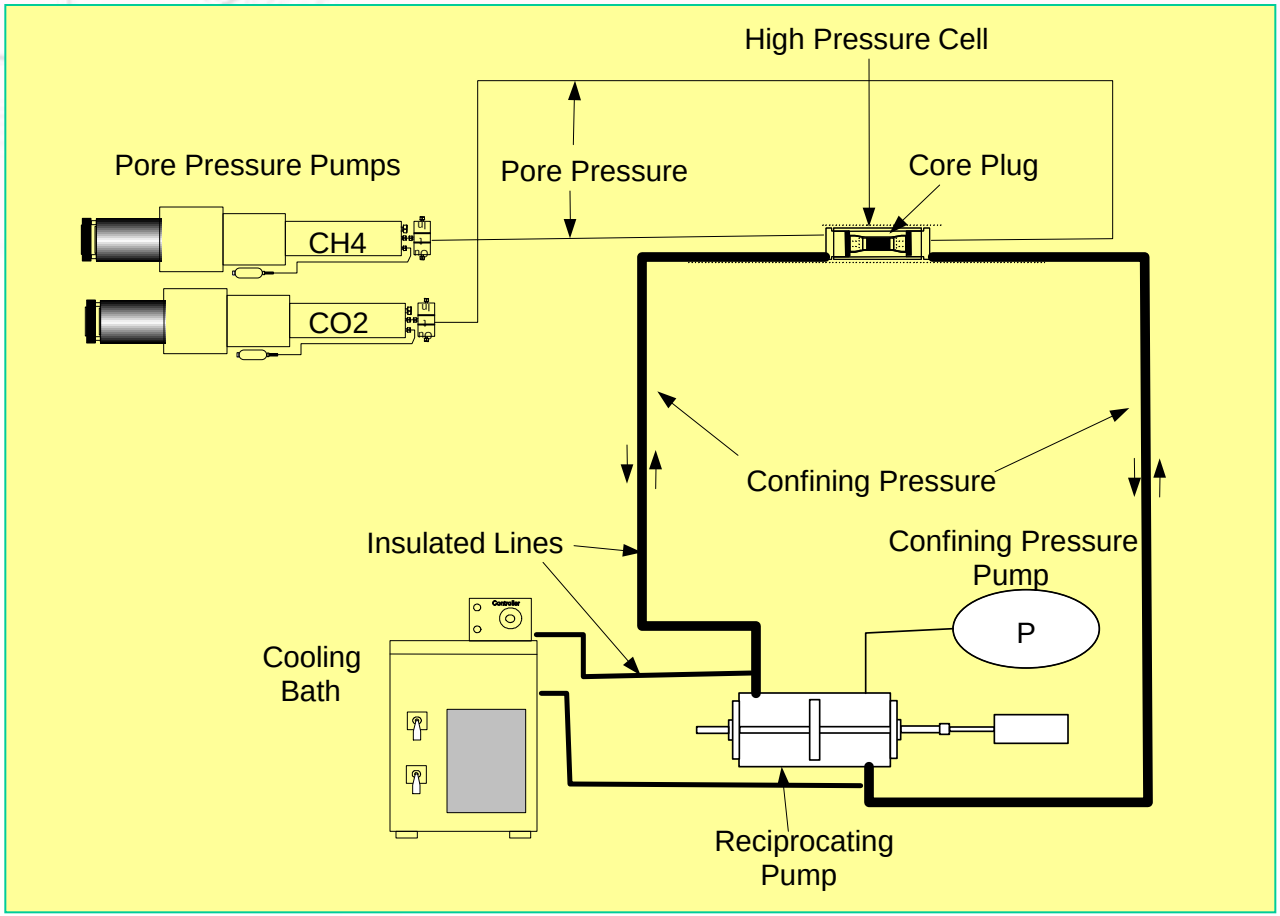
RESEARCH OBJECTIVES

- Form hydrates in porous media
  - Create laboratory size equivalents of actual hydrate reservoirs

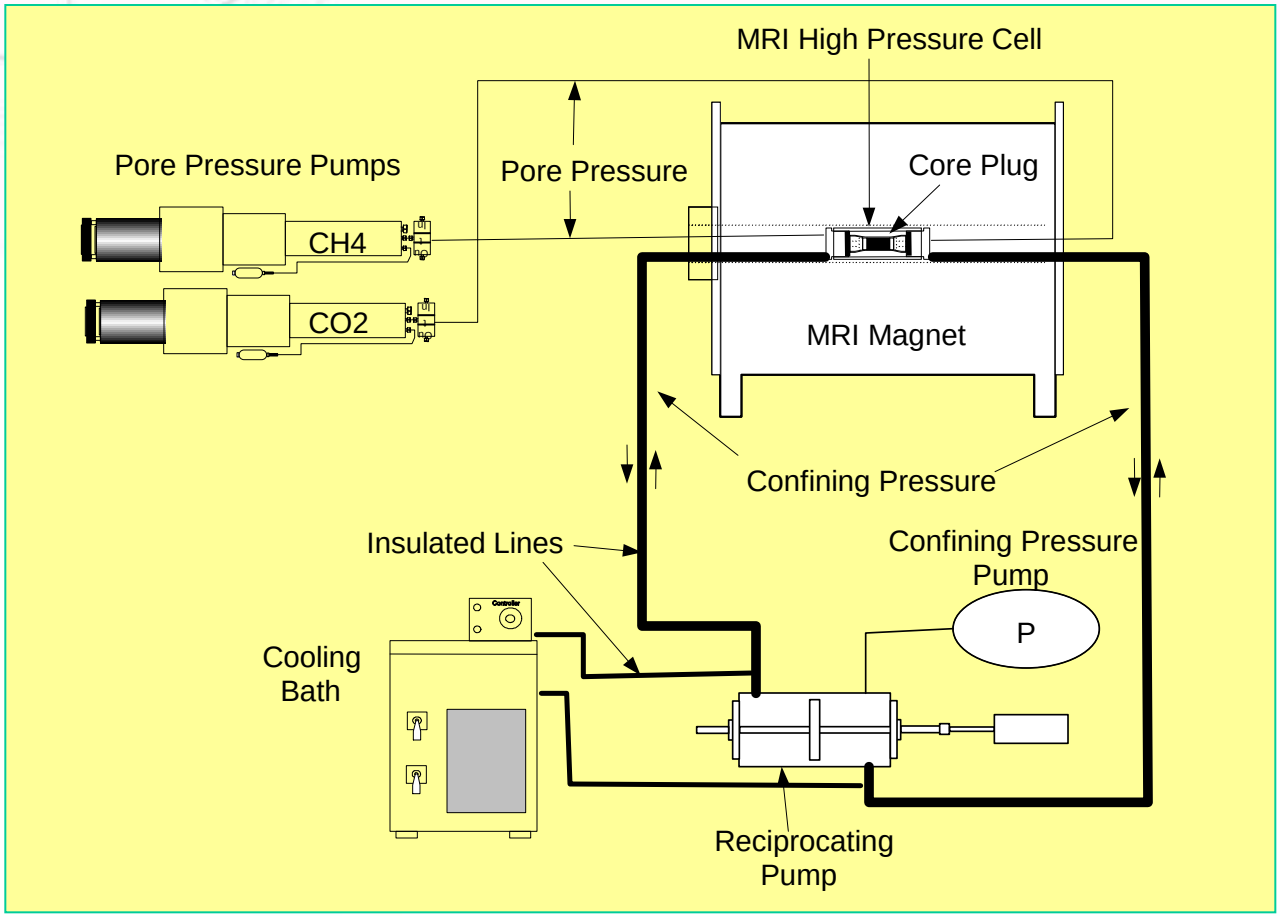
Test CH_4-CO_2 exchange process

-does it work?

Experimental Setup



Experimental Setup



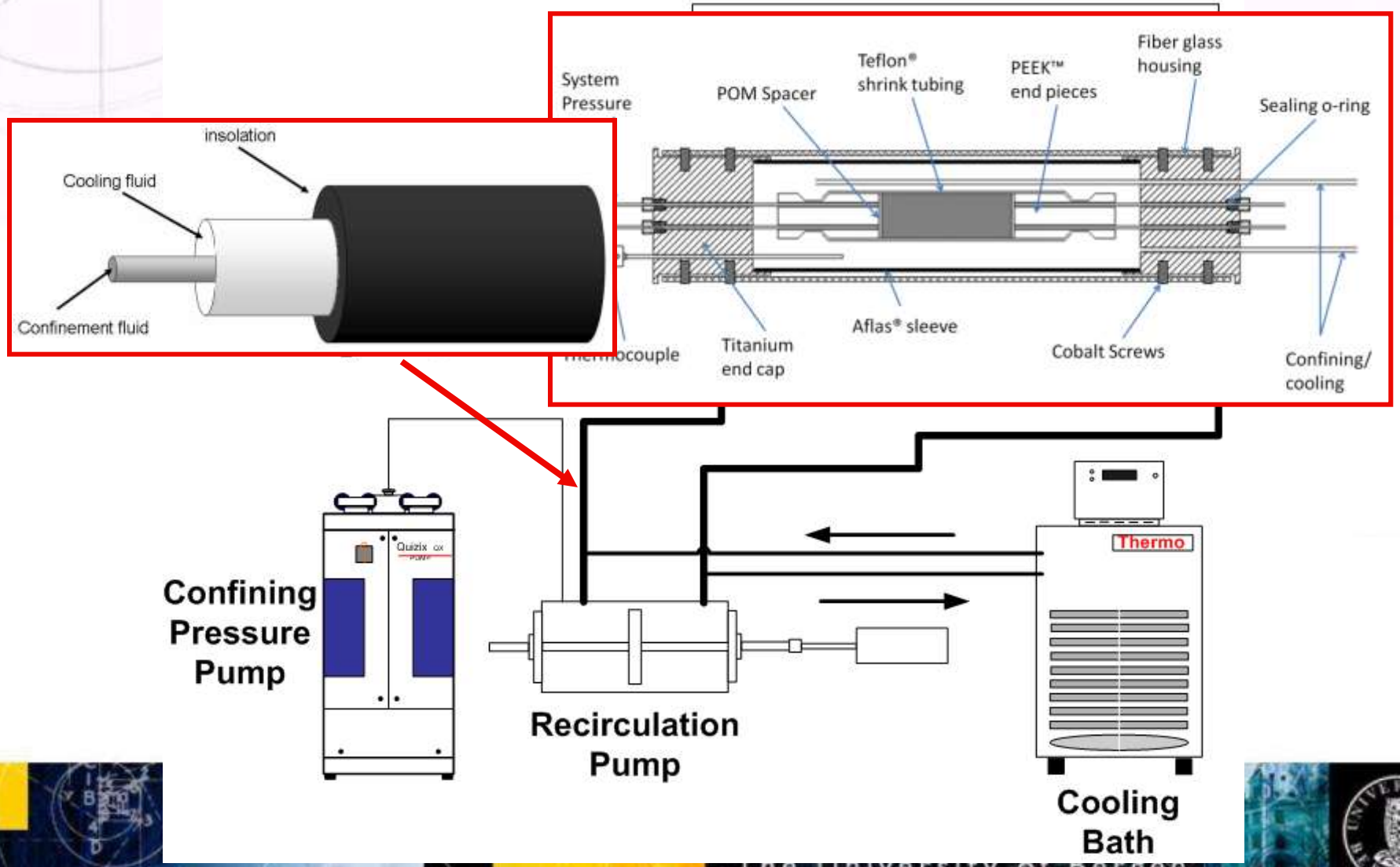
Monitor P-V-T and MRI Intensity

During Hydrate Formation

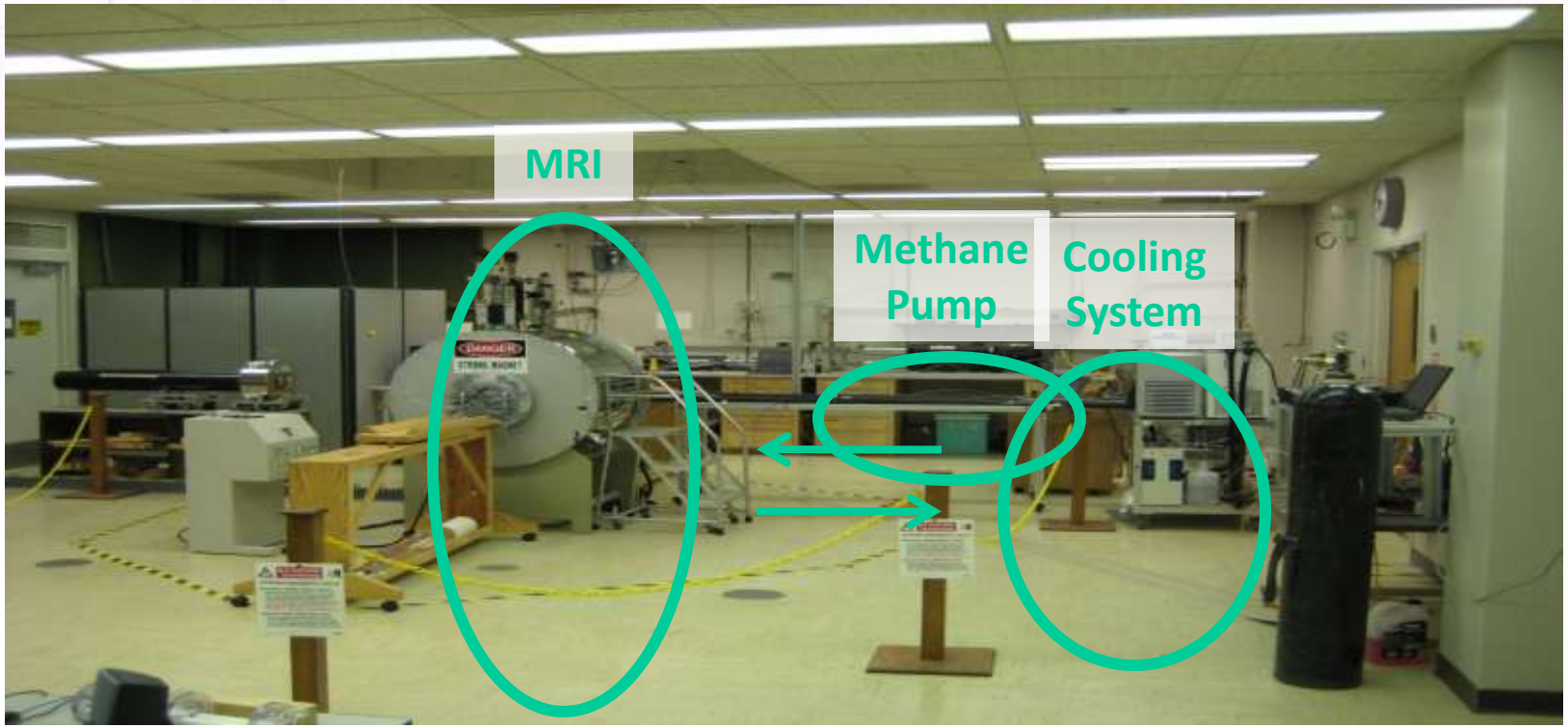
HYDRATE FORMATION IN POROUS MEDIA

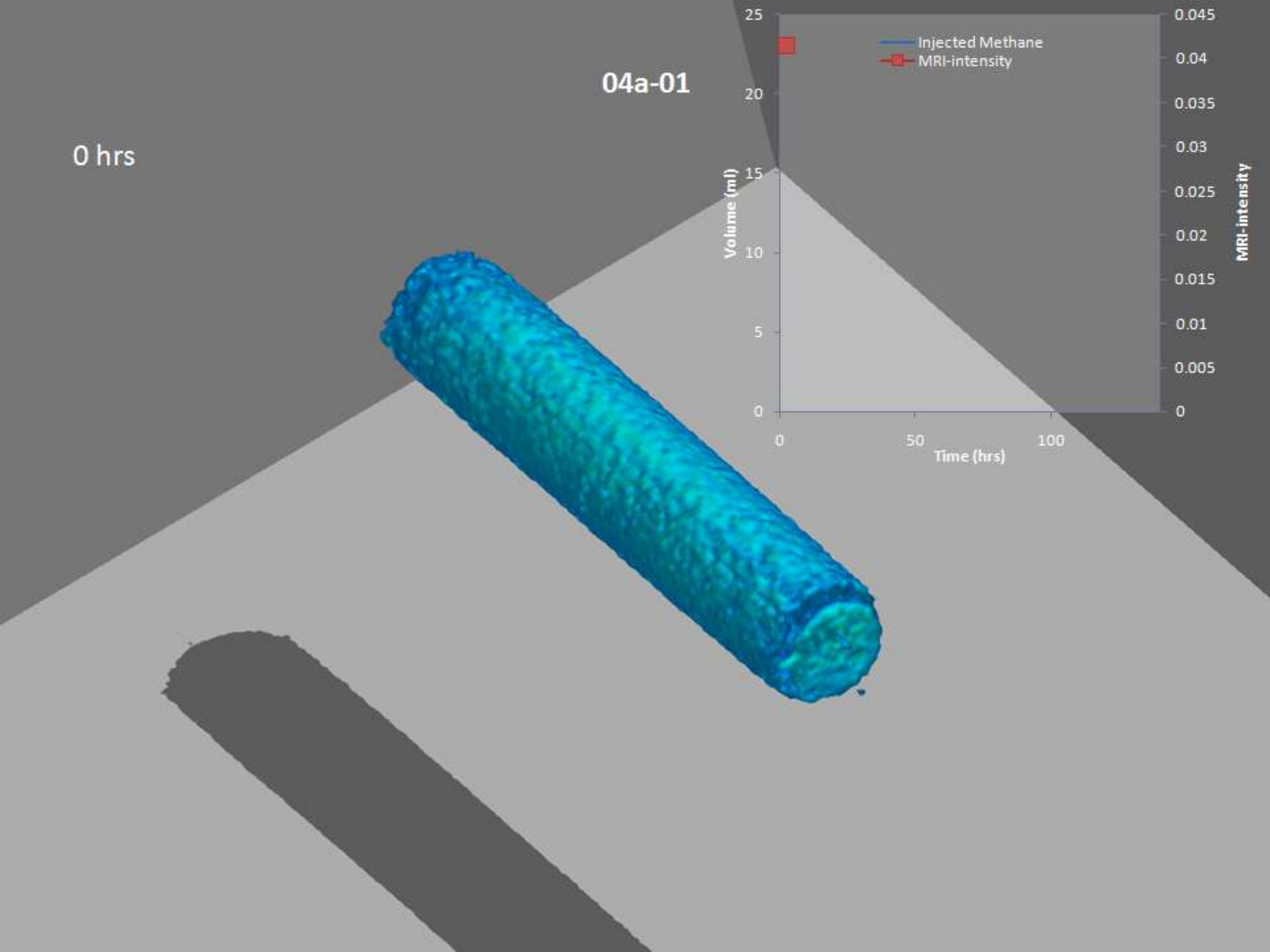
- Objective
  - Create laboratory size equivalent of hydrate reservoir
- P
  Sa

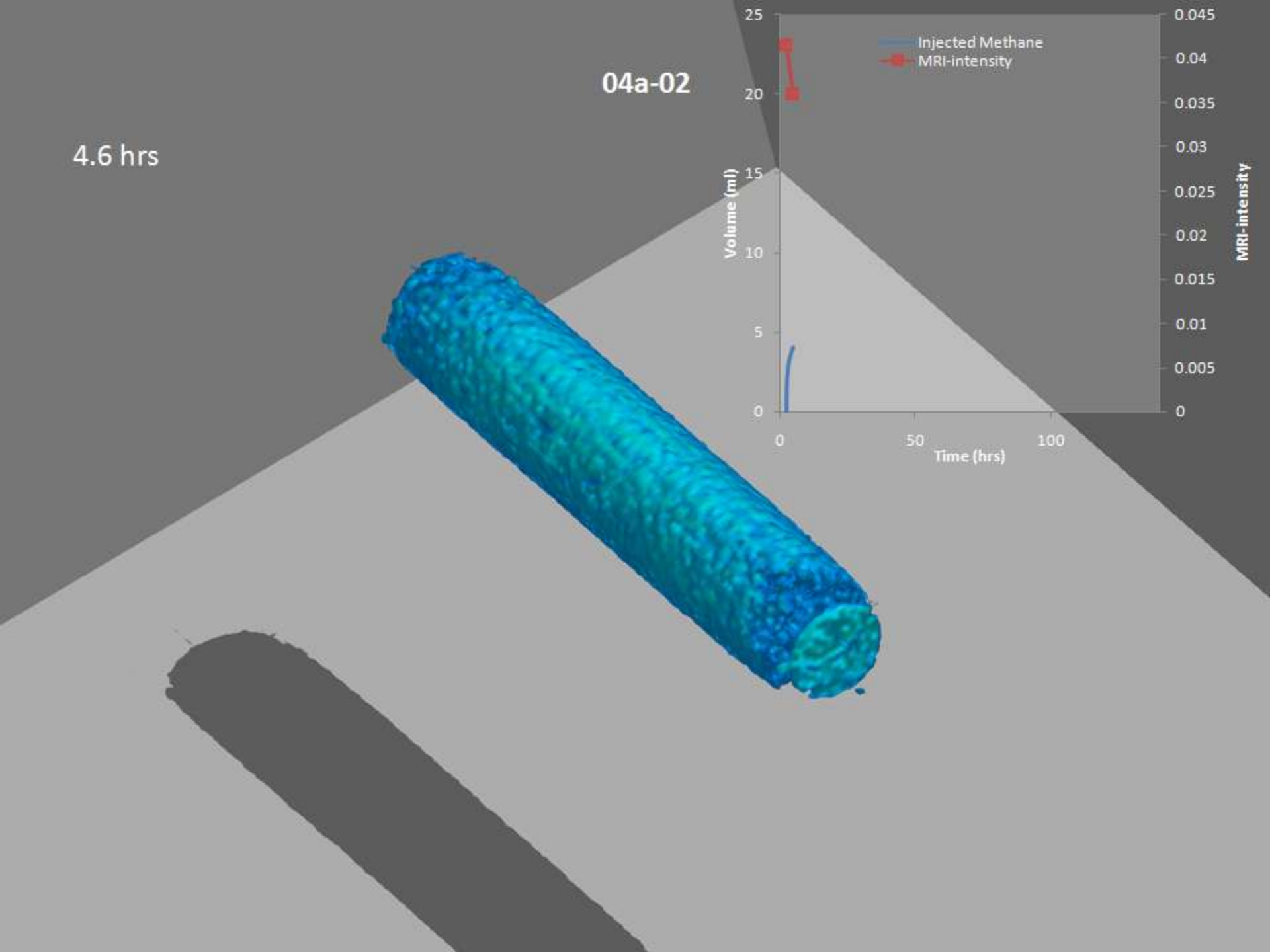
EXPERIMENTAL SETUP

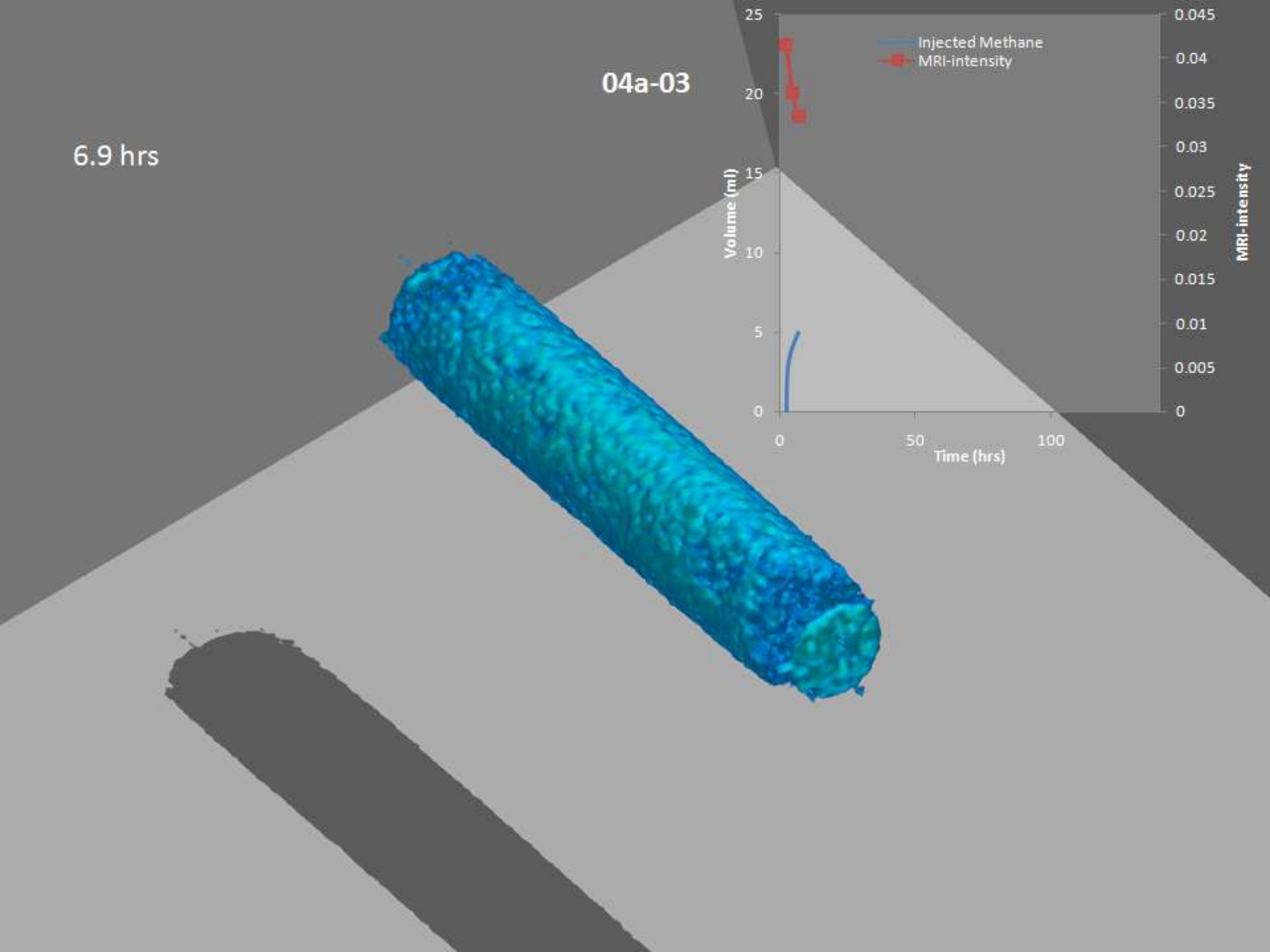


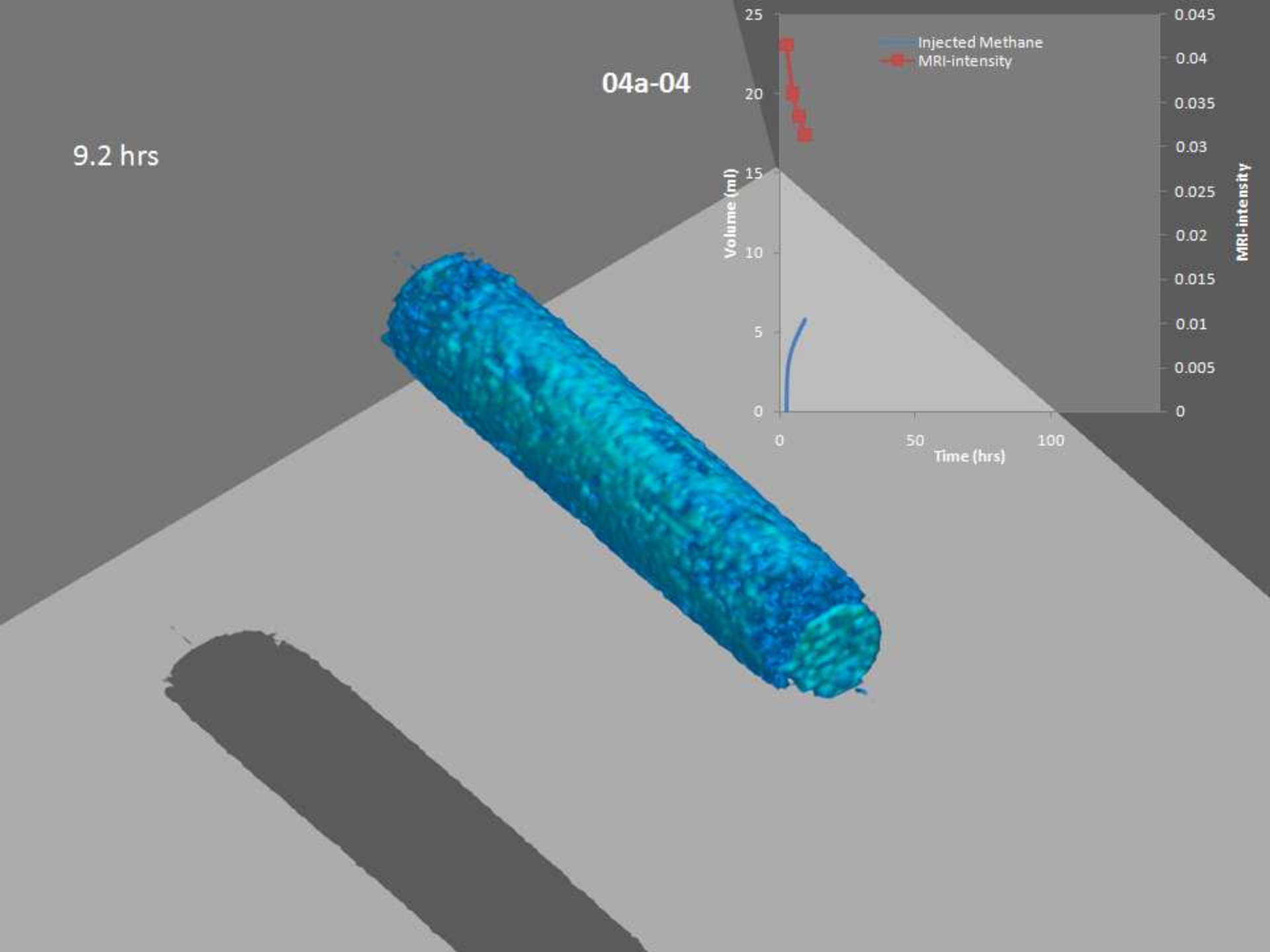
EXPERIMENTAL SETUP

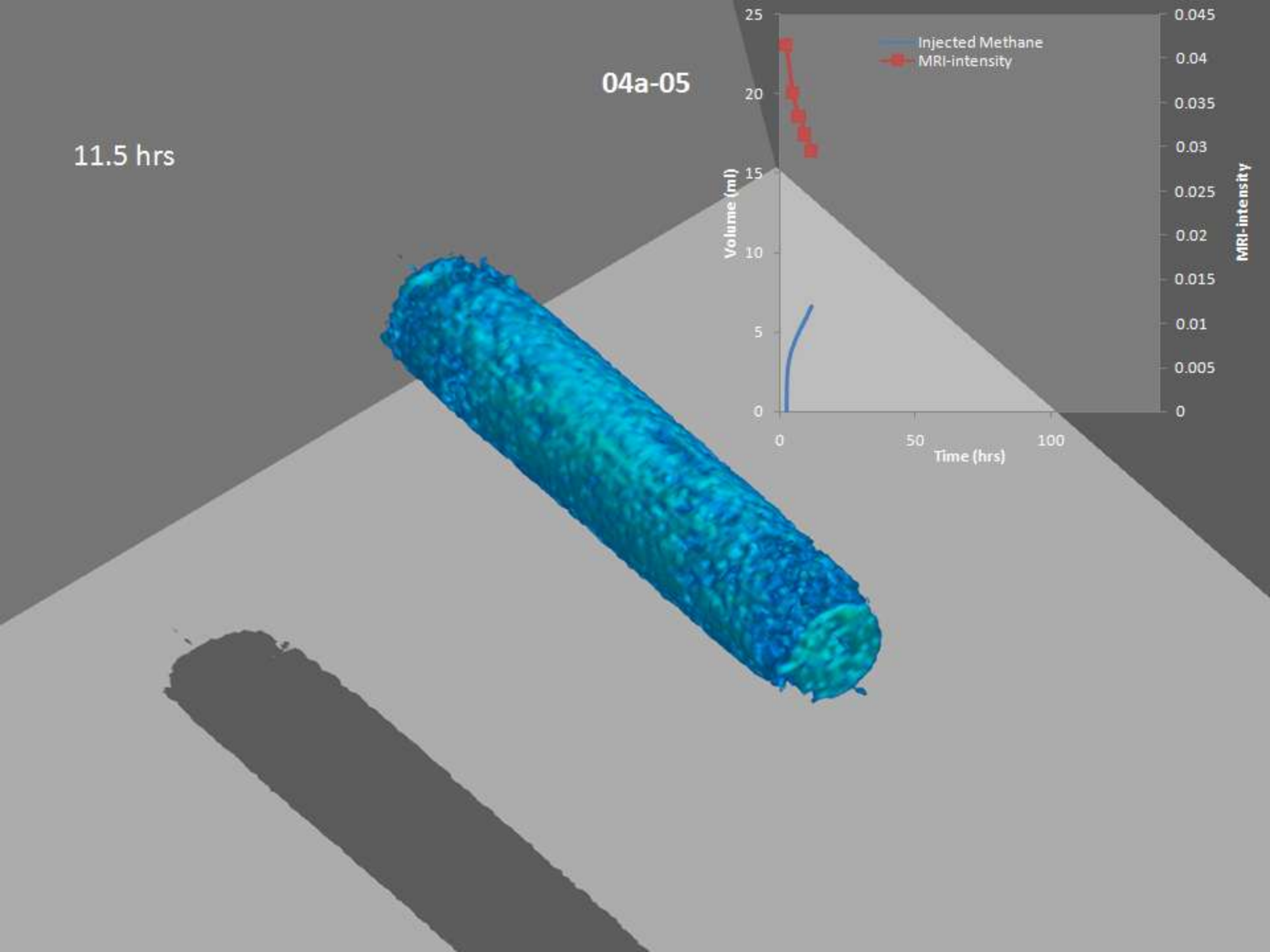


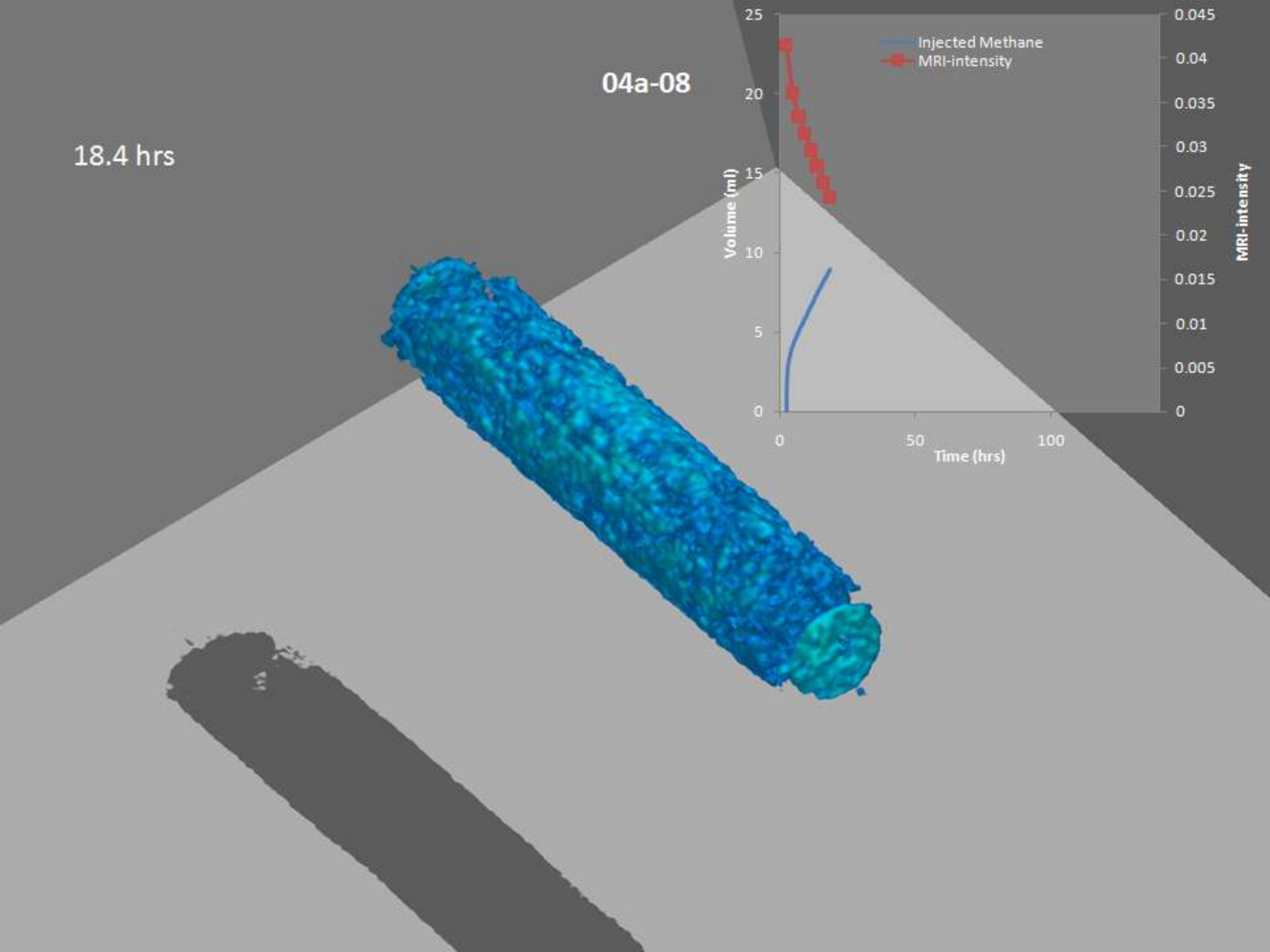

04a-01
0 hrs
Injected Methane
MRI-intensity
Volume (ml)
MRI-intensity
Time (hrs)
0
5
10
15
20
25
0
50
100
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
0.04
0.045

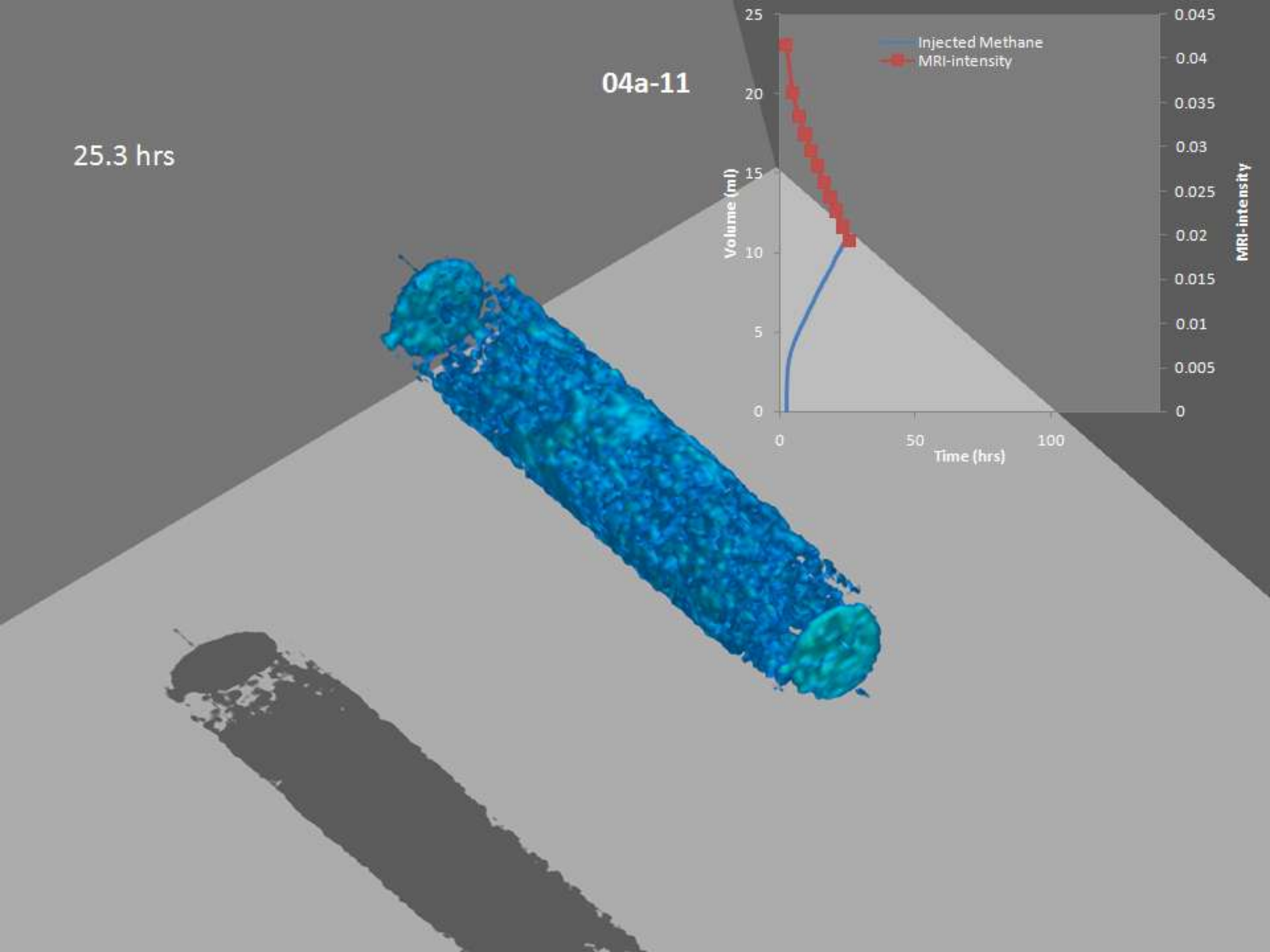

04a-02
4.6 hrs
Injected Methane
MRI-intensity
Volume (ml)
MRI-intensity
Time (hrs)
0
5
10
15
20
25
0
50
100
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
0.04
0.045

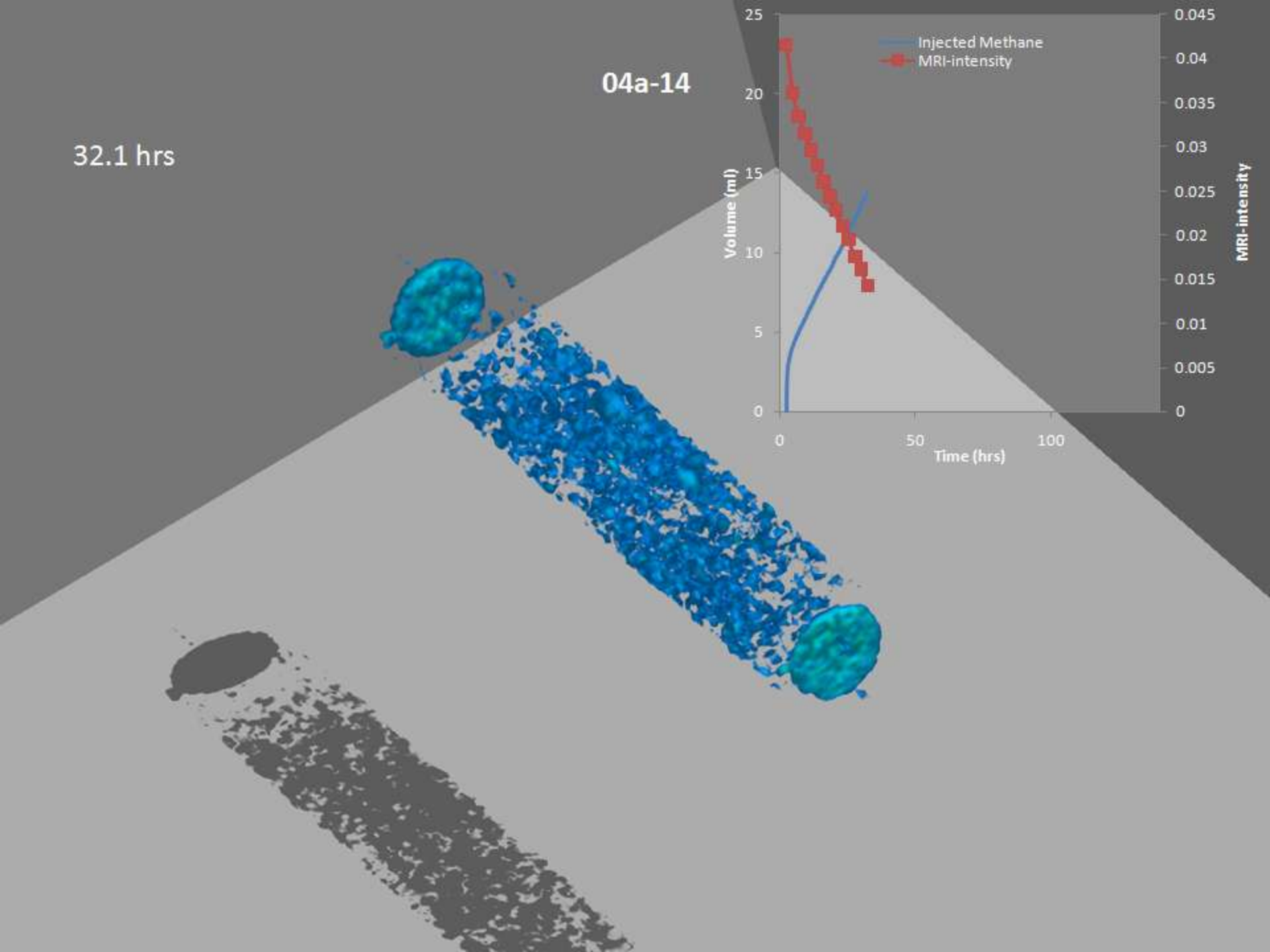

04a-03
6.9 hrs
Injected Methane
MRI-intensity
Volume (ml)
MRI-intensity
Time (hrs)
0
5
10
15
20
25
0
50
100
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
0.04
0.045

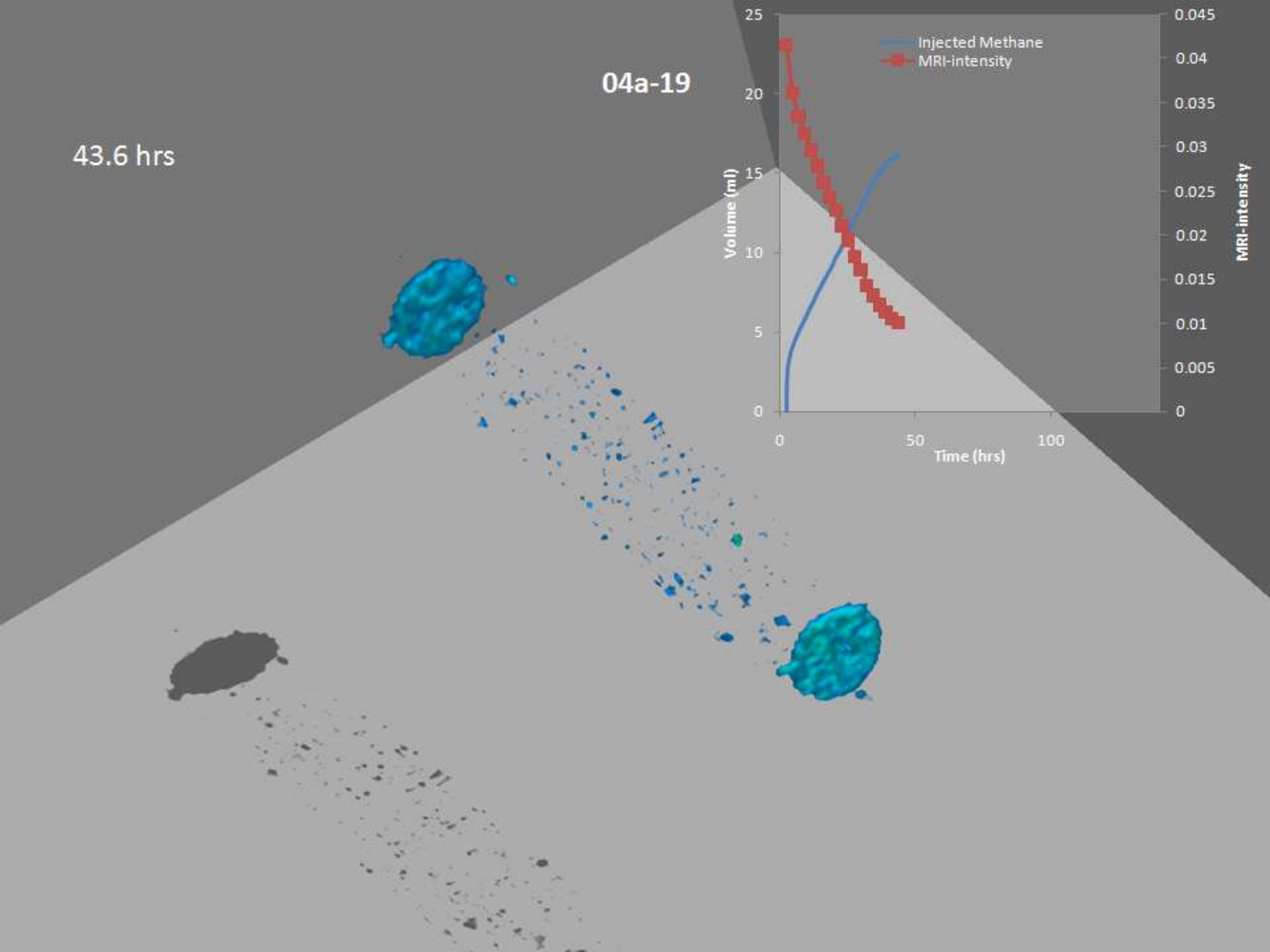

04a-04
9.2 hrs
Injected Methane
MRI-intensity
Volume (ml)
MRI-intensity
Time (hrs)
0
5
10
15
20
25
0
50
100
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
0.04
0.045

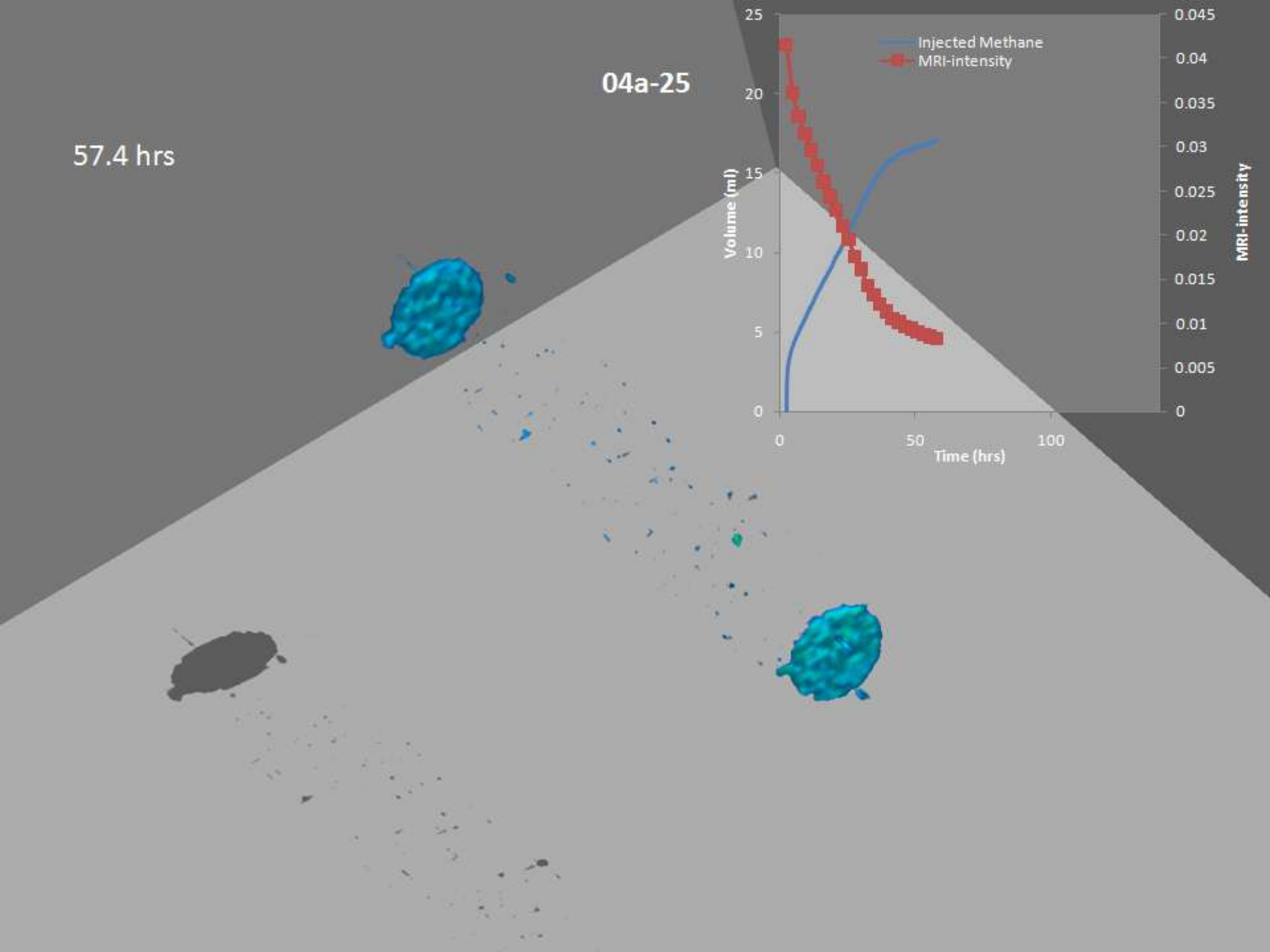

04a-05
11.5 hrs
Injected Methane
MRI-intensity
Volume (ml)
MRI-intensity
Time (hrs)
0
5
10
15
20
25
0
50
100
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
0.04
0.045

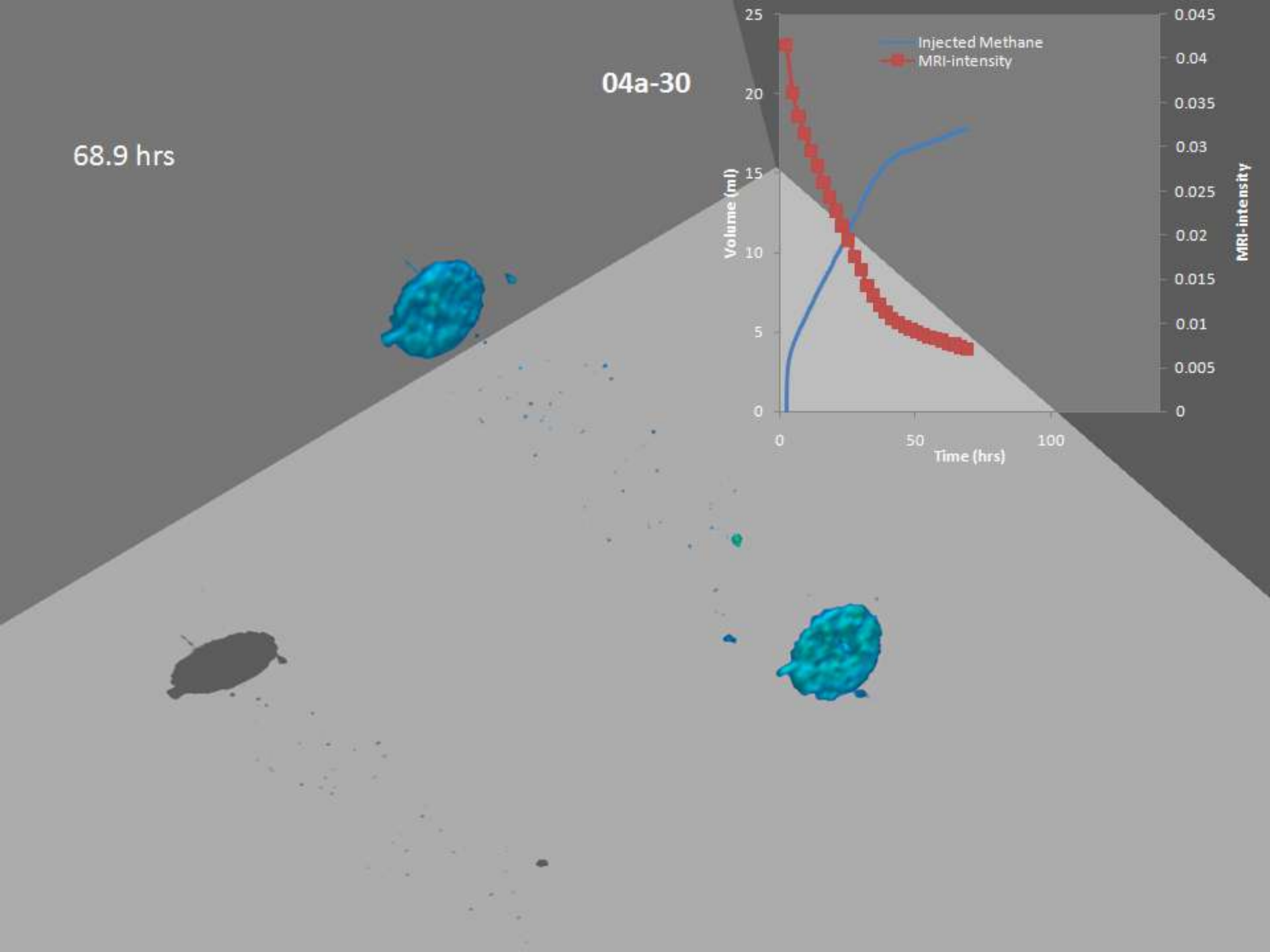

04a-08
18.4 hrs
Injected Methane
MRI-intensity
Volume (ml)
MRI-intensity
Time (hrs)
0
5
10
15
20
25
0
50
100
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
0.04
0.045

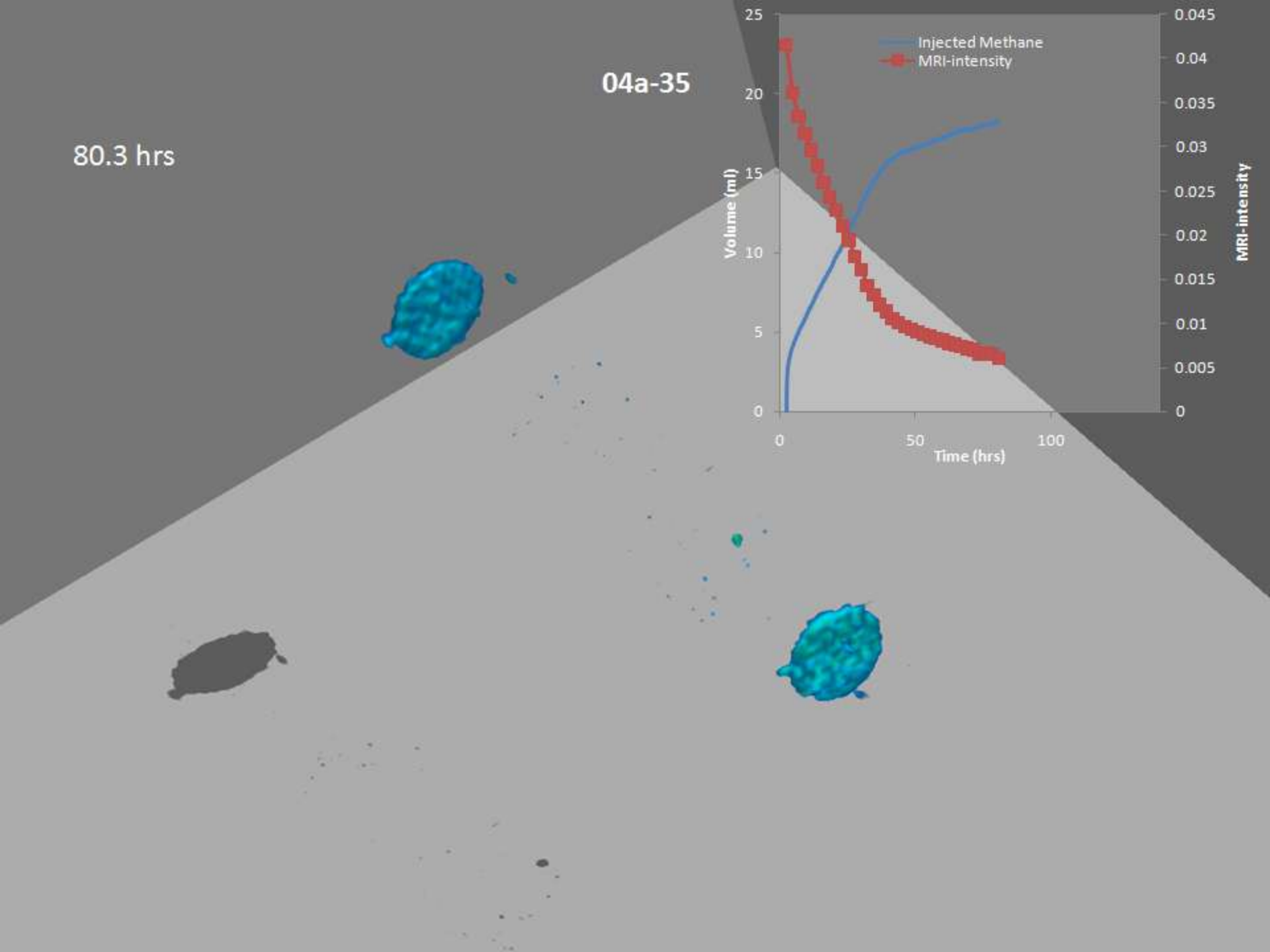

04a-11
25.3 hrs
Injected Methane
MRI-intensity
Volume (ml)
MRI-intensity
Time (hrs)
0
5
10
15
20
25
0
50
100
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
0.04
0.045

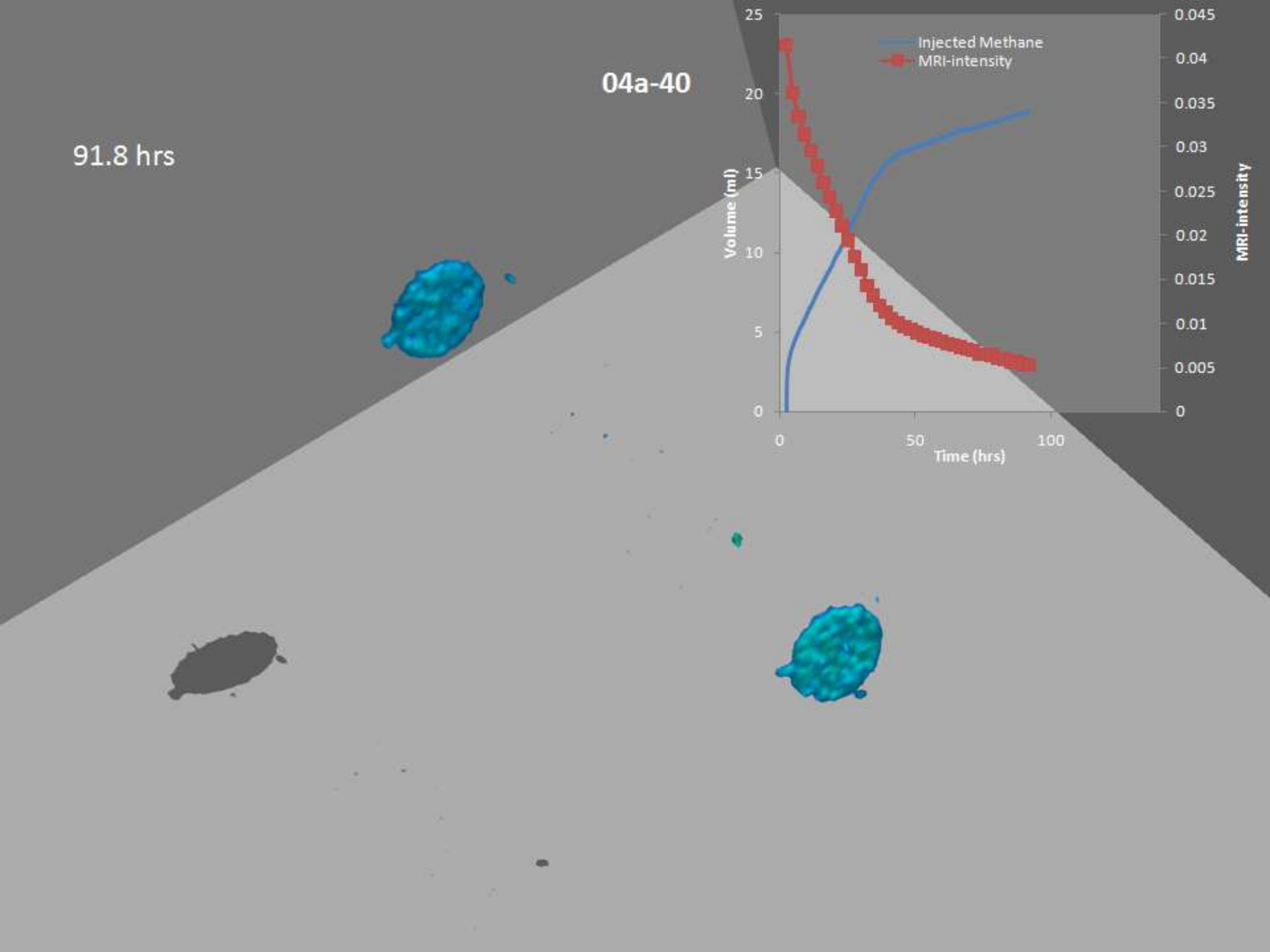

04a-14
32.1 hrs
Injected Methane
MRI-intensity
Volume (ml)
MRI-intensity
Time (hrs)
0
5
10
15
20
25
0
50
100
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
0.04
0.045

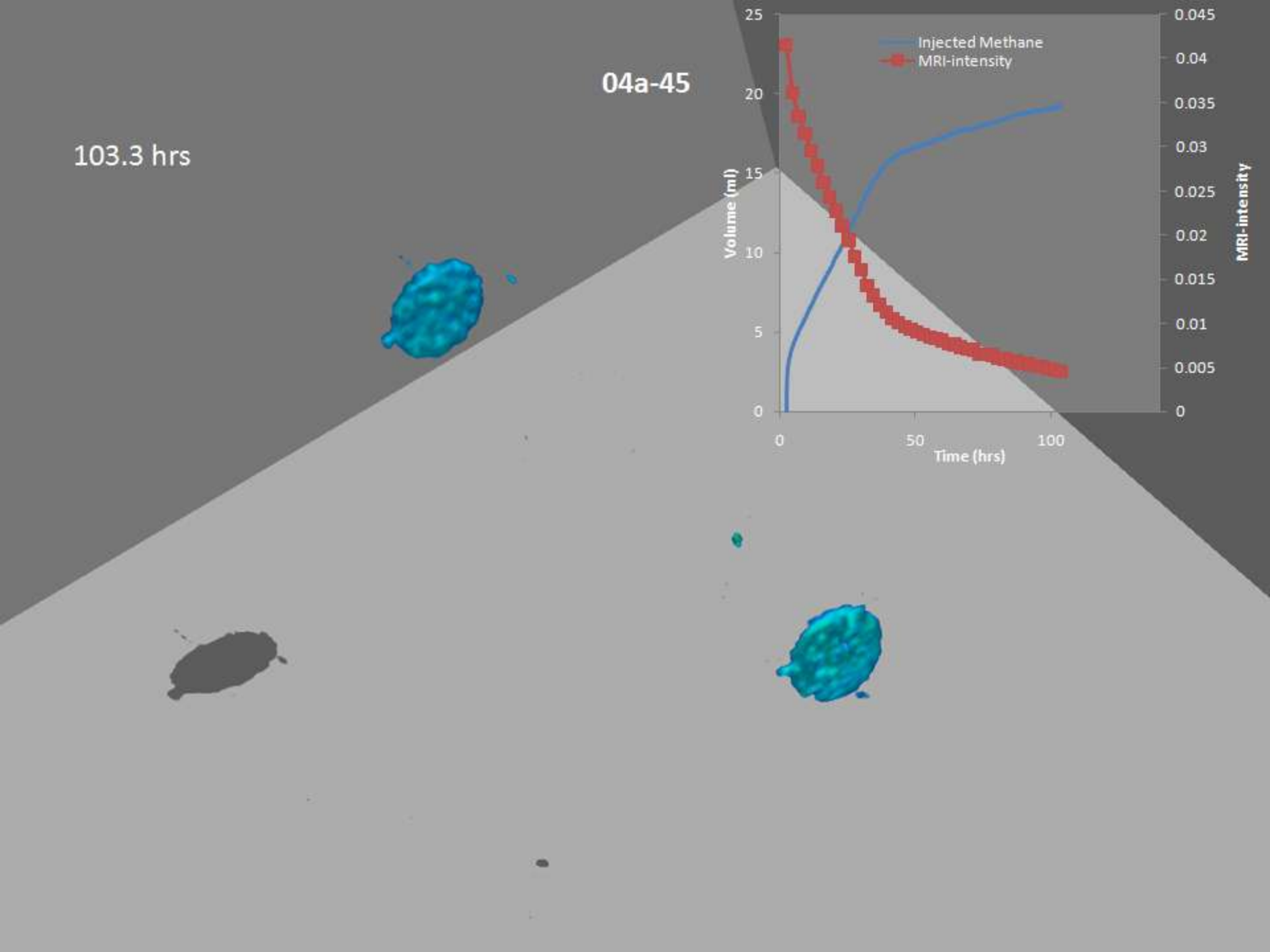

04a-19
43.6 hrs
Injected Methane
MRI-intensity
Volume (ml)
MRI-intensity
Time (hrs)
0
5
10
15
20
25
0
50
100
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
0.04
0.045

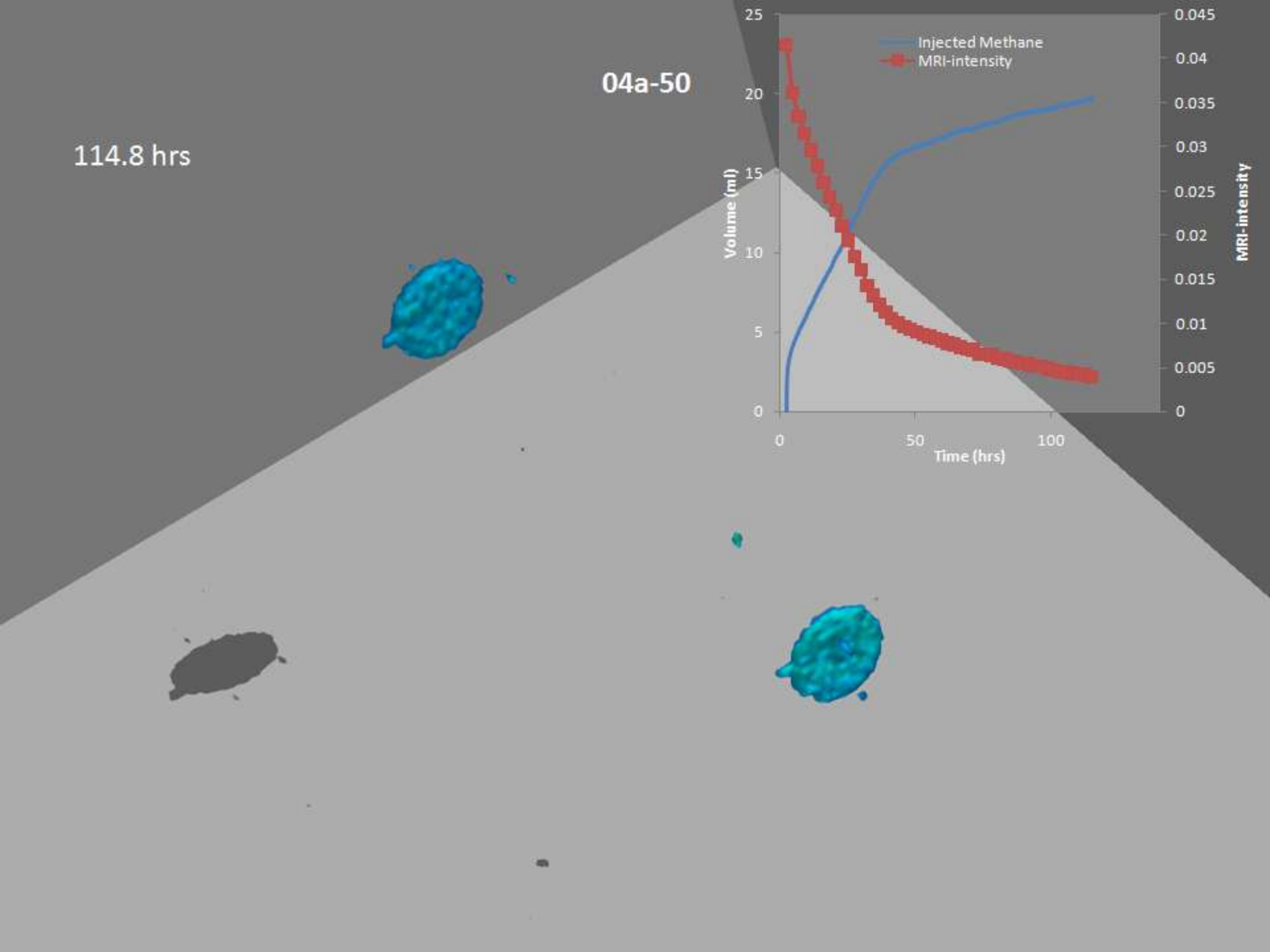

04a-25
57.4 hrs
Injected Methane
MRI-intensity
Volume (ml)
MRI-intensity
Time (hrs)
0
5
10
15
20
25
0
50
100
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
0.04
0.045

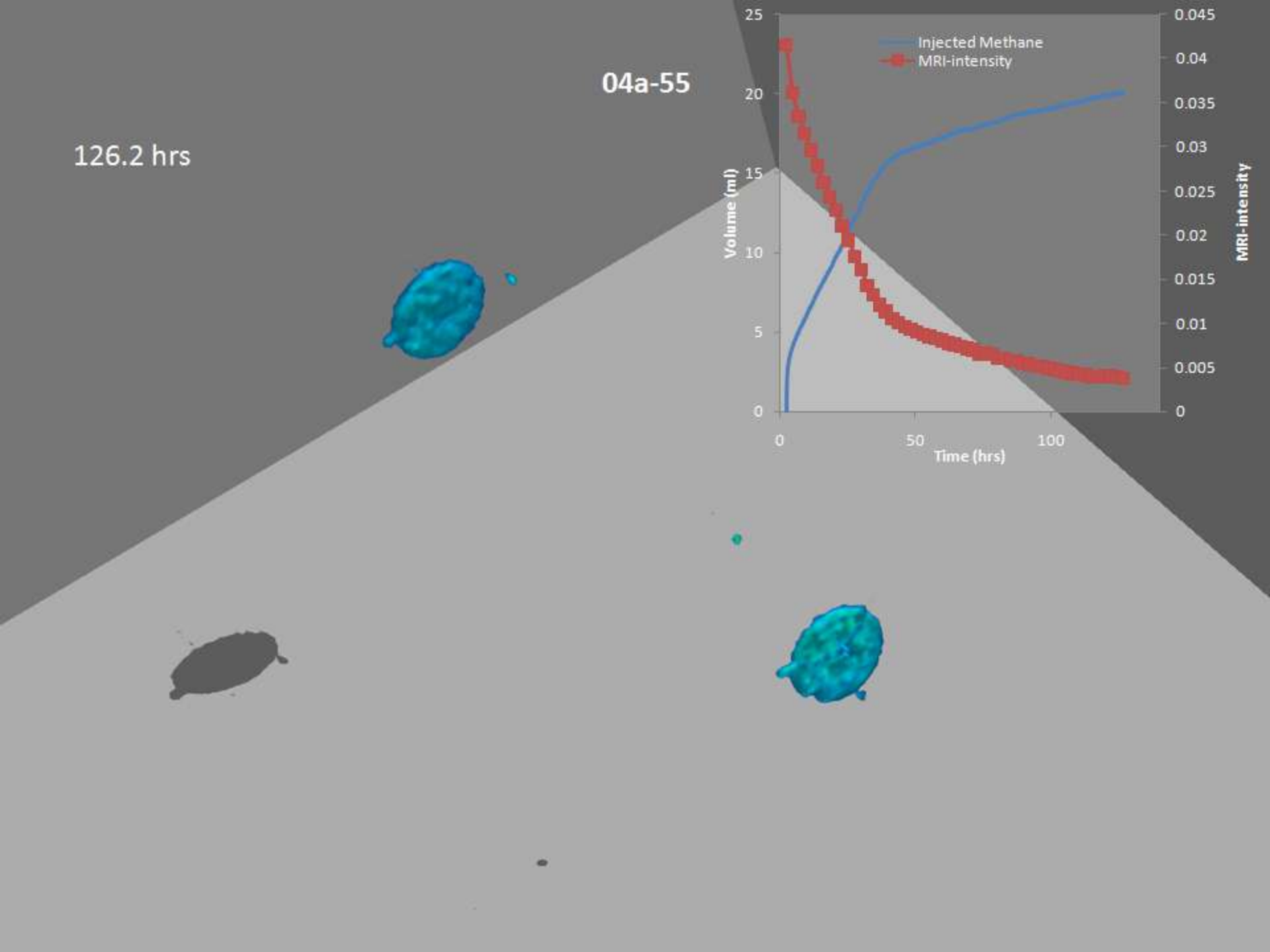

04a-30
68.9 hrs
Injected Methane
MRI-intensity
Volume (ml)
MRI-intensity
Time (hrs)
0
5
10
15
20
25
0
50
100
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
0.04
0.045


04a-35
80.3 hrs
Injected Methane
MRI-intensity
Volume (ml)
MRI-intensity
Time (hrs)
0
5
10
15
20
25
0
50
100
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
0.04
0.045


04a-40
91.8 hrs
Injected Methane
MRI-intensity
Volume (ml)
MRI-intensity
Time (hrs)
0
5
10
15
20
25
0
50
100
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
0.04
0.045

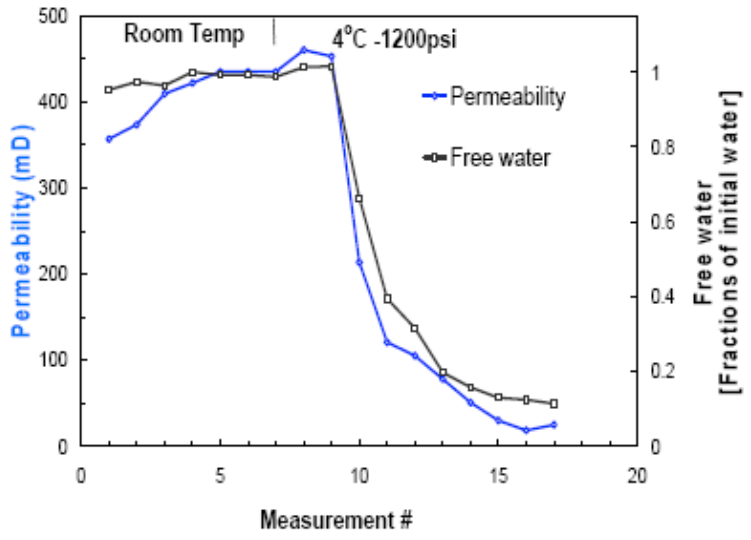

04a-45
103.3 hrs
Injected Methane
MRI-intensity
Volume (ml)
MRI-intensity
Time (hrs)
0
5
10
15
20
25
0
50
100
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
0.04
0.045


04a-50
114.8 hrs
Injected Methane
MRI-intensity
Volume (ml)
MRI-intensity
Time (hrs)
0
5
10
15
20
25
0
50
100
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
0.04
0.045


04a-55
126.2 hrs
Injected Methane
MRI-intensity
Volume (ml)
MRI-intensity
Time (hrs)
0
5
10
15
20
25
0
50
100
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
0.04
0.045

Gas Permeability

- MRI Intensity Loss Indicates Hydrate Formation. Correlates with Permeability Decrease.



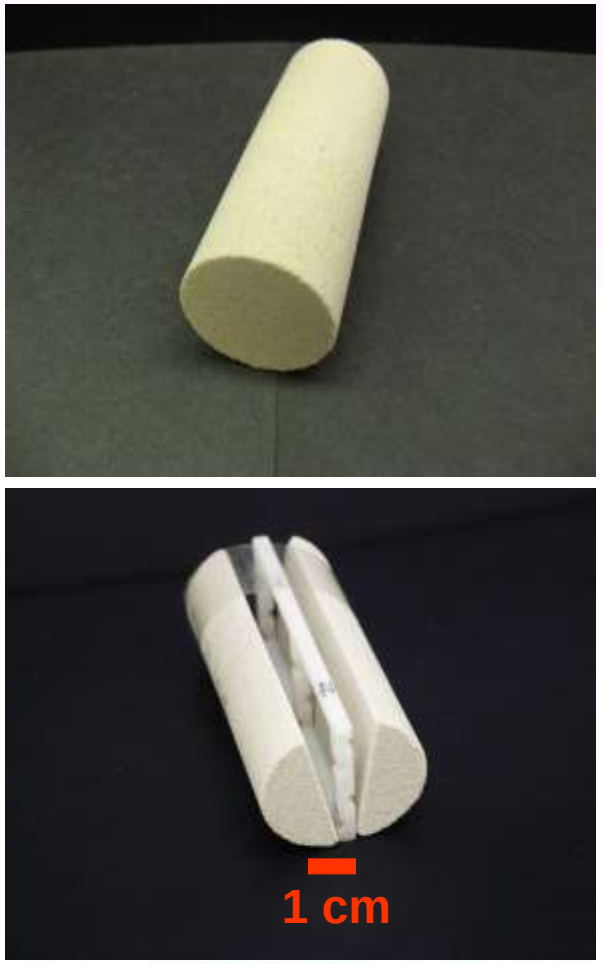
Exp #	$S_w/S_g/S_h$	k_{app}(mD)
1	33/67/0	670
	2/57/41	143
2	34/66/0	410
	11/60/29	217
3	47/53/0	356
	11/44/45	25
4	48/52/0	157
	3/41/56	13
5	51/49/0	115
	4/36/60	4
6	36/64/0	248
	2/40/58	7

CO2 replacement exp.

Bentheim Sandstone

Φ =20-25%, k~1.1 D

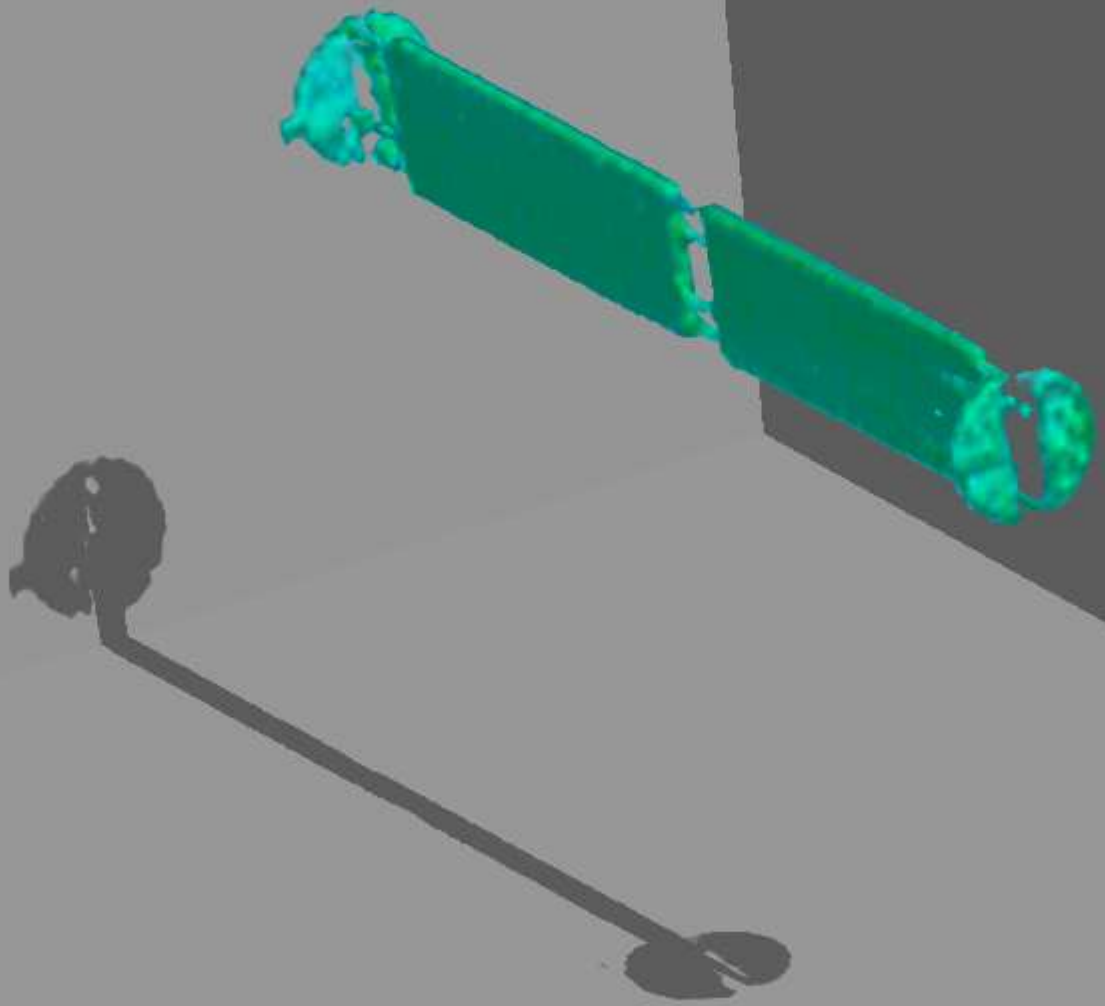
- Whole Core
- Longitudinal Cut – Fitted Spacer Simulates Open Fracture.



33-03

0.0 hrs

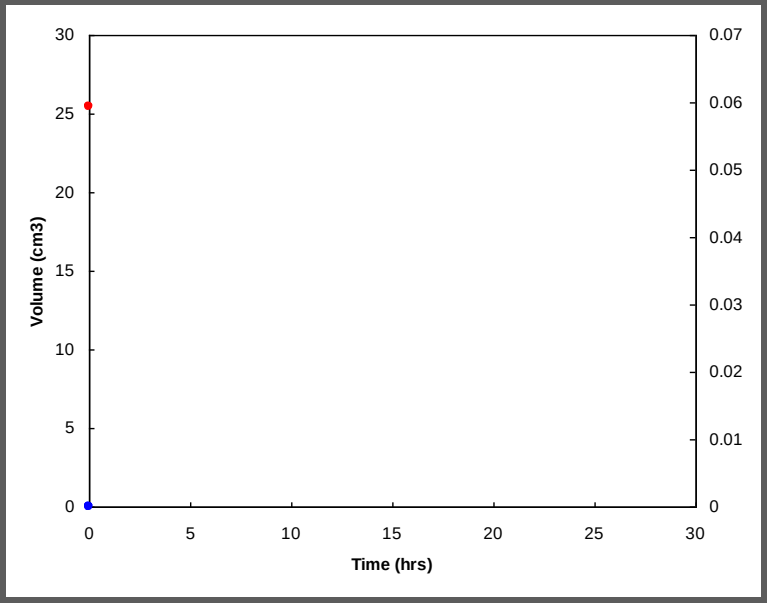
Methane in Spacer



33-07

0.0 hrs

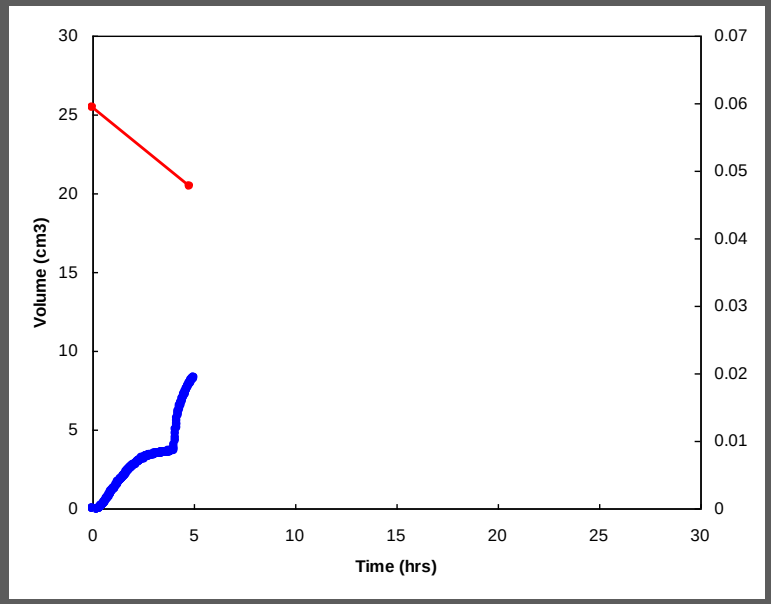
Sw=0.5 + Methane



33a-01

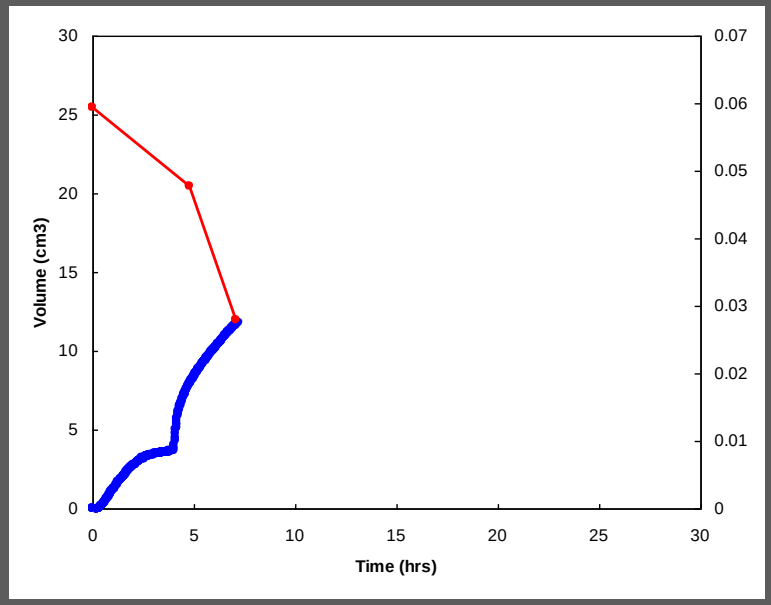
5.0 hrs

Cooling Starts



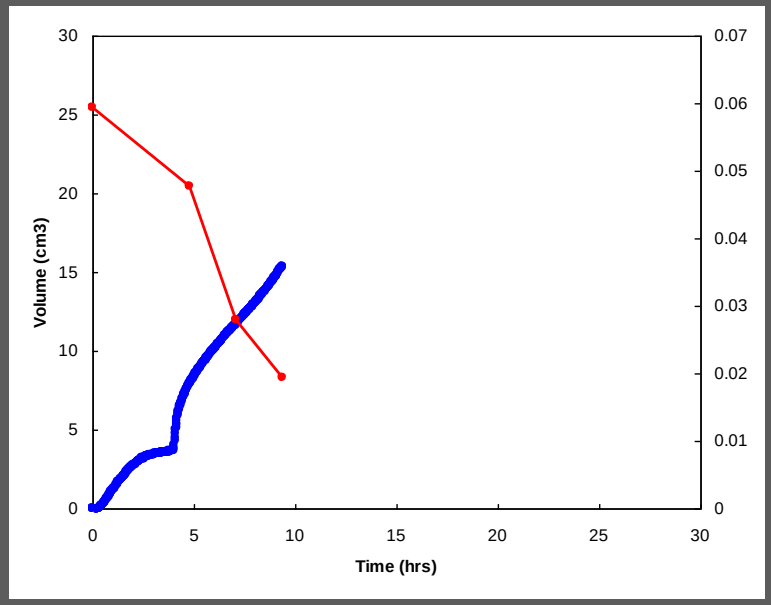
33c-01

7.2 hrs


30
25
20
15
10
5
0
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
Volume (cm3)
0
5
10
15
20
25
30
Time (hrs)

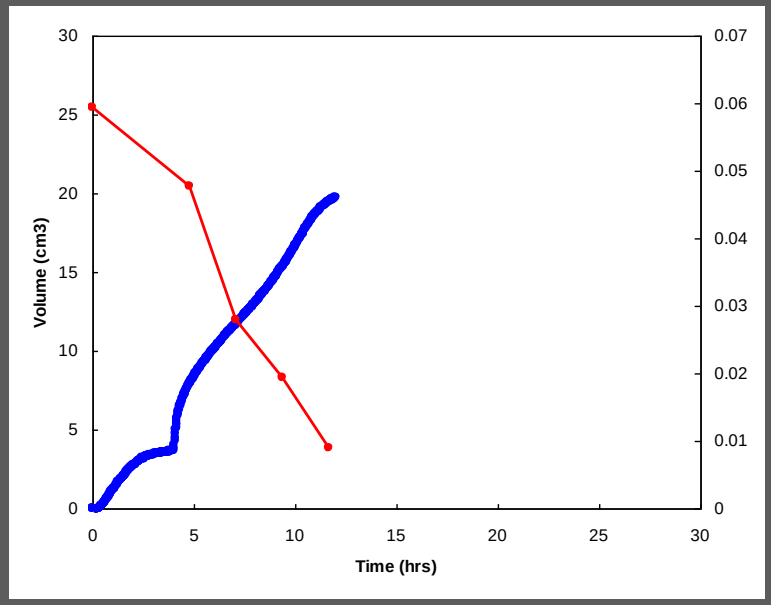
33c-02

9.4 hrs



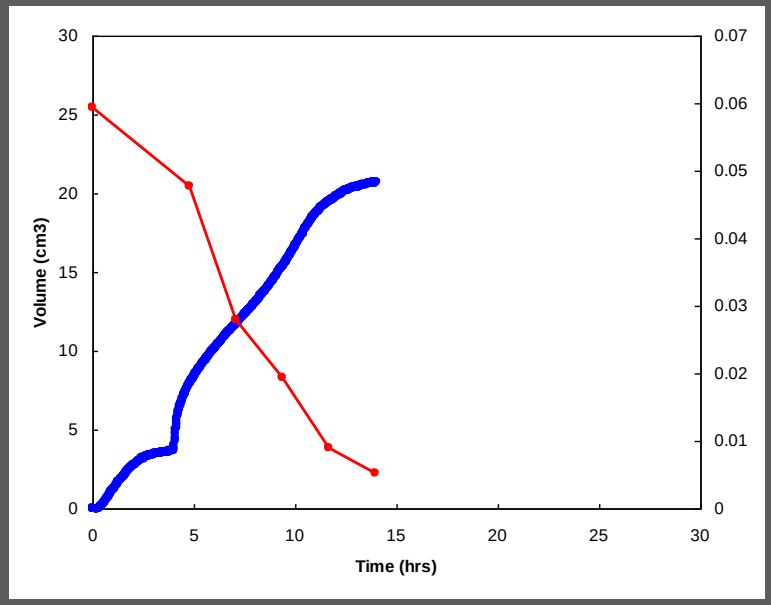
33c-03

12.0 hrs



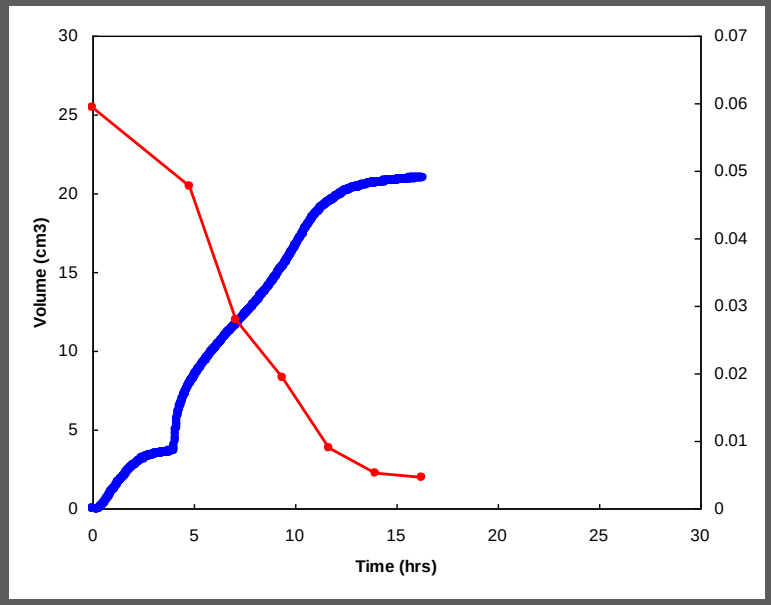
33c-04

14.0 hrs



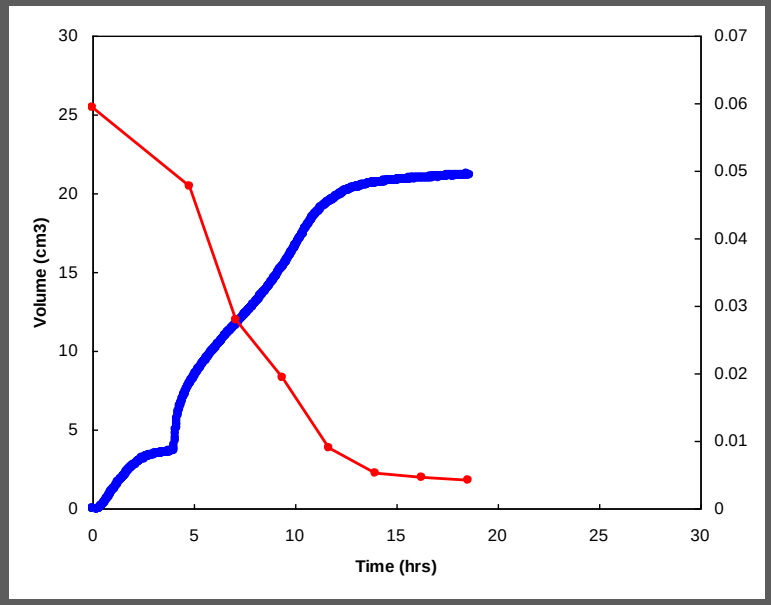
33c-05

16.3 hrs



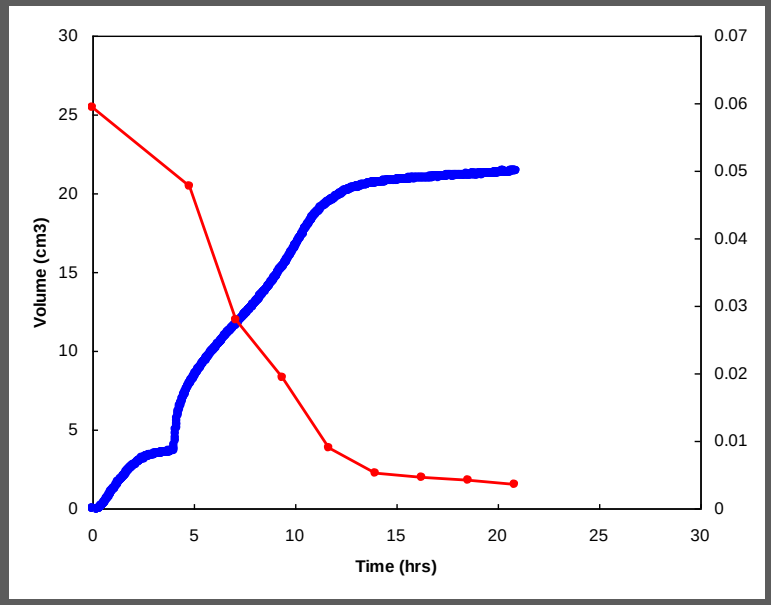
33c-06

18.6 hrs



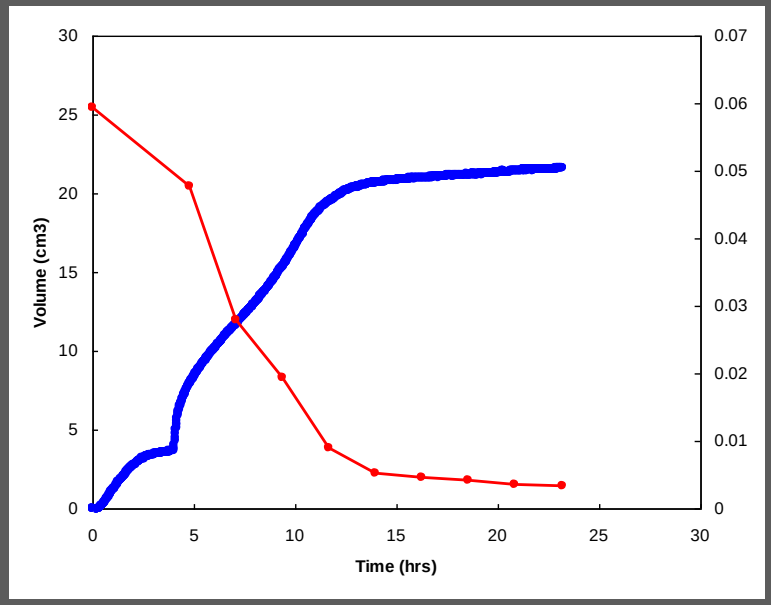
33c-07

20.9 hrs



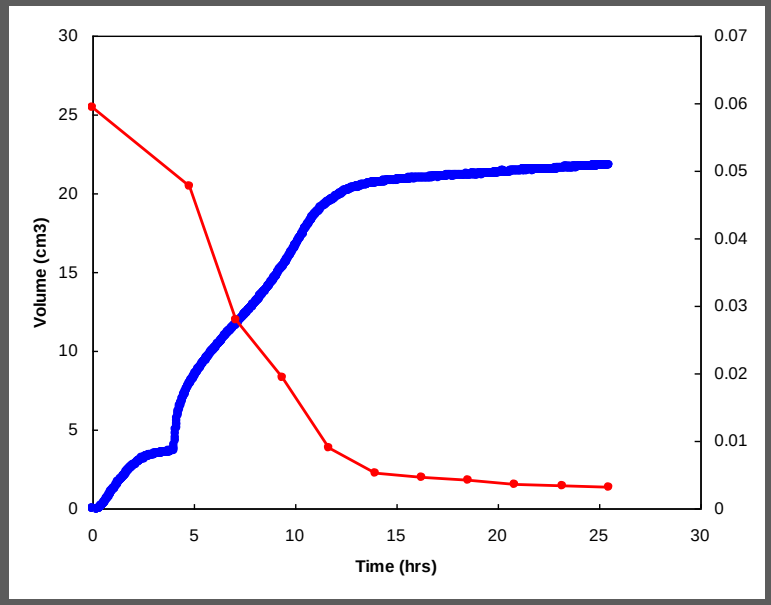
33c-08

23.2 hrs



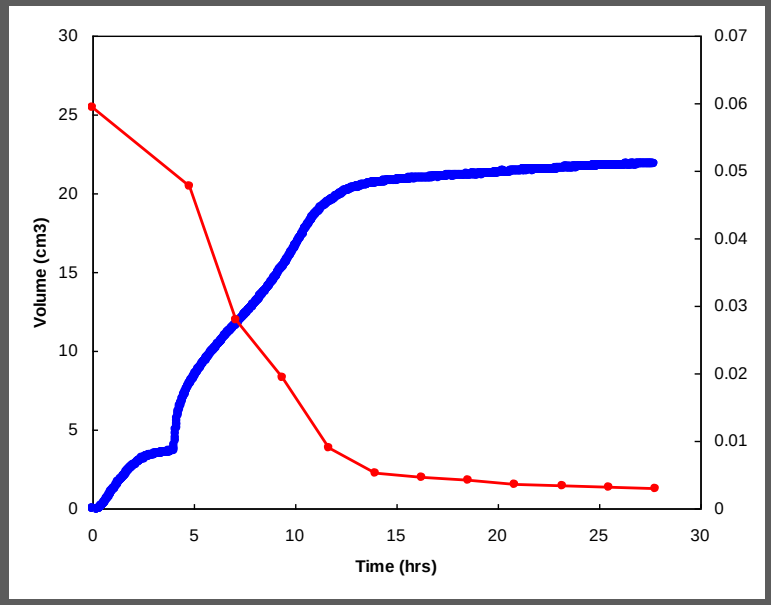
33c-09

25.5 hrs



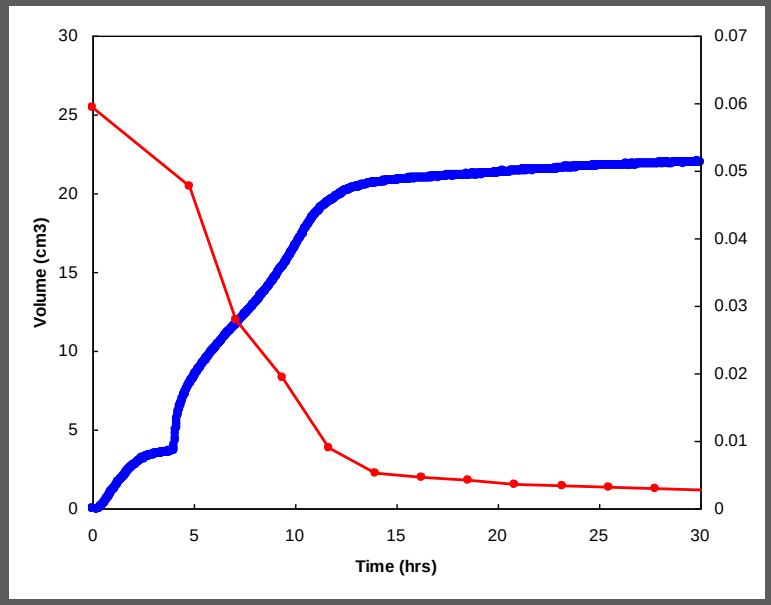
33c-10

27.7 hrs



33c-11

30.0 hrs



Core Halves Saturated with hydrate

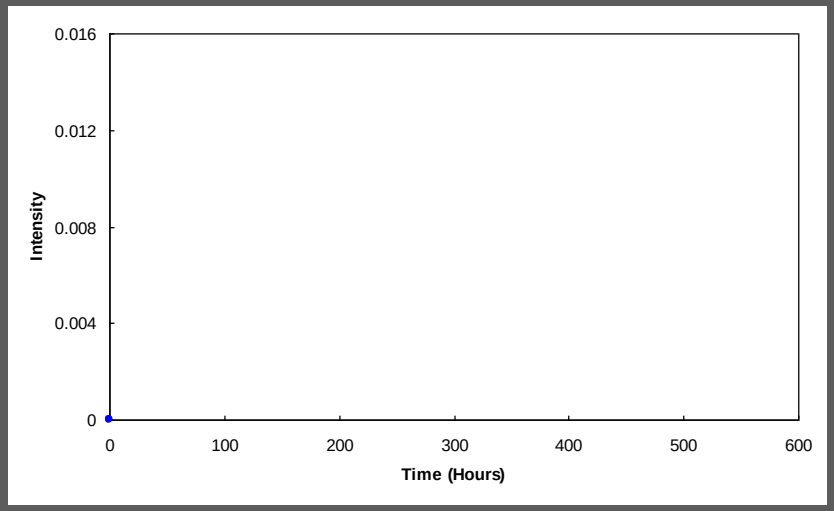
CH_4 - CO_2 Production Scenario

- Replace CH_4 in Hydrate Structure with CO_2.
- Keys are Understanding of Rates of Exchange and Recovery Efficiency.

CH4 Production Experiments

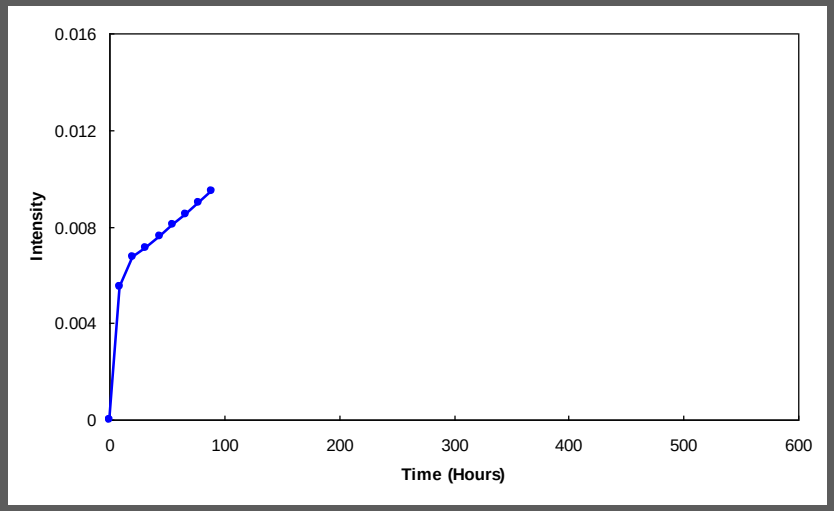
- Flush Spacer with CO_2 and Wait.
- Connected to CO_2 Reservoir
- Monitor MRI Intensity in Spacer.

0.0 hrs


0.016
0.012
0.008
0.004
0
Intensity
0
100
200
300
400
500
600
Time (Hours)

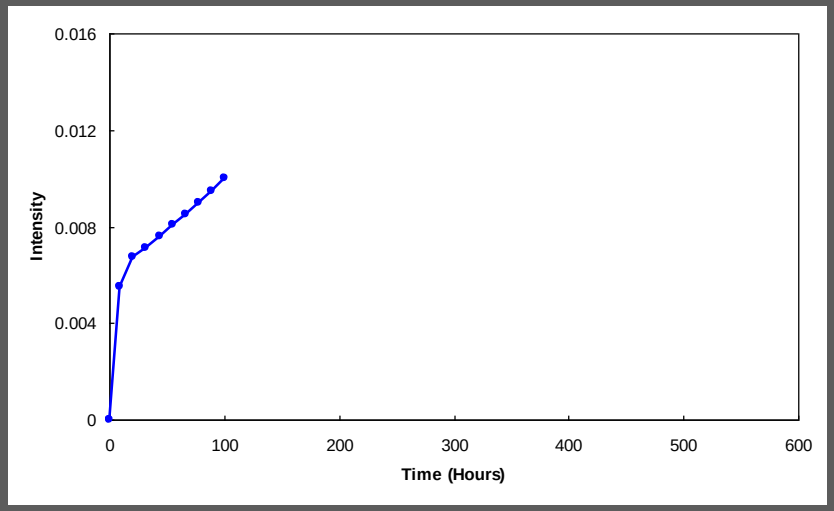
34b-07

89.2 hrs



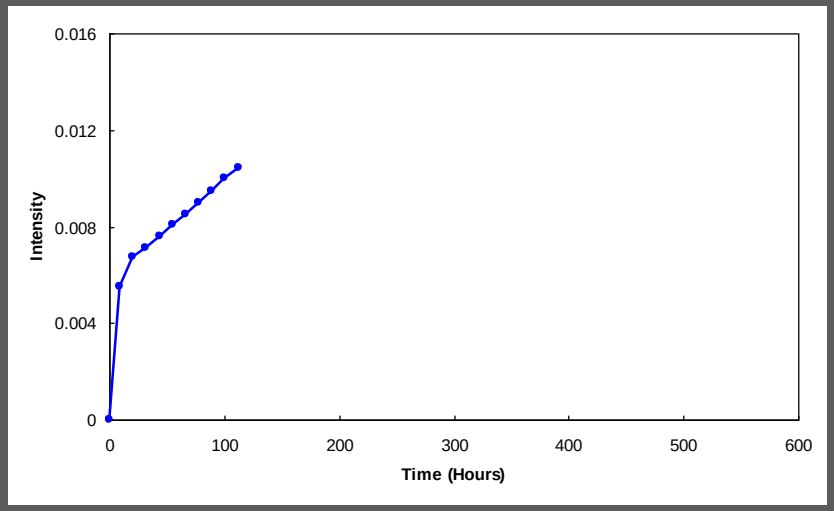
34b-08

100.6 hrs



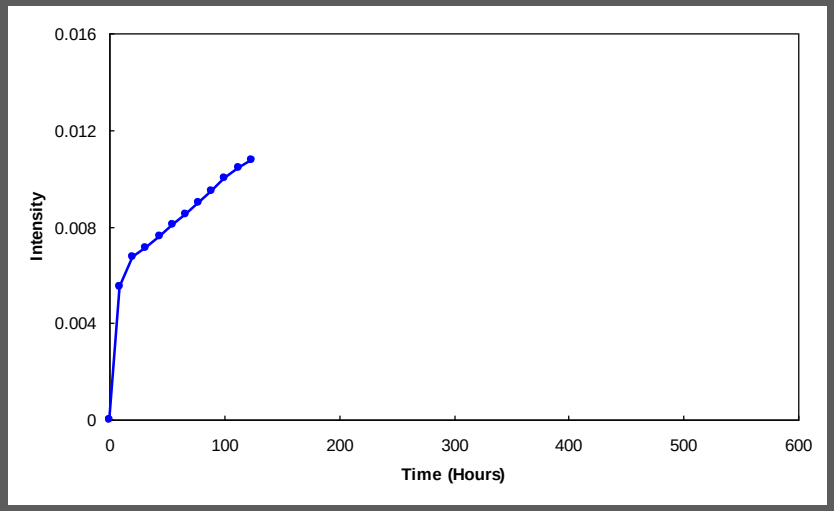
34b-09

112.1 hrs



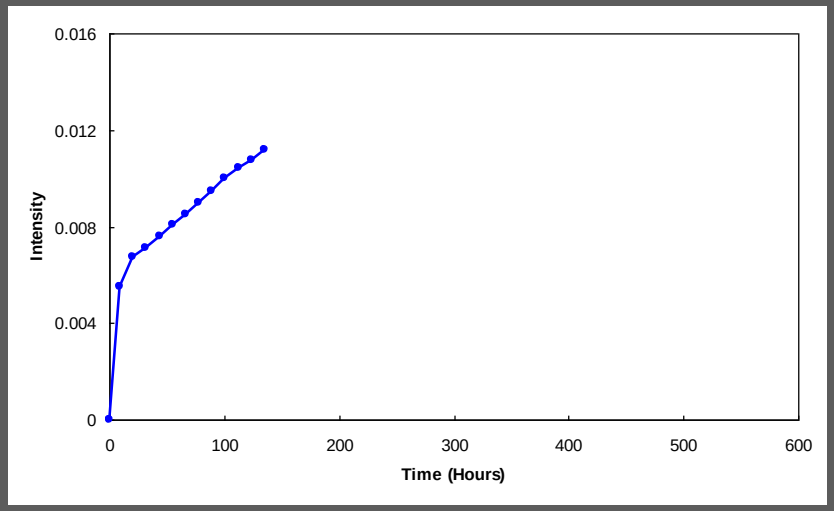
34b-10

123.5 hrs



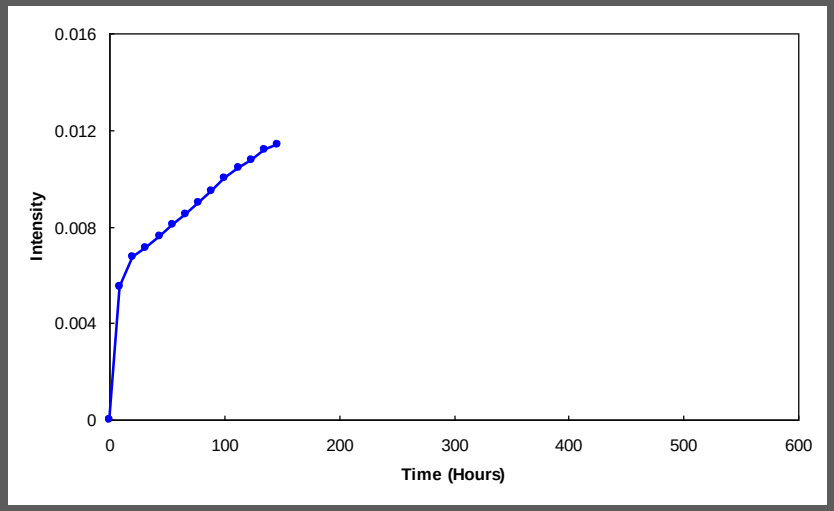
34b-11

135.0 hrs



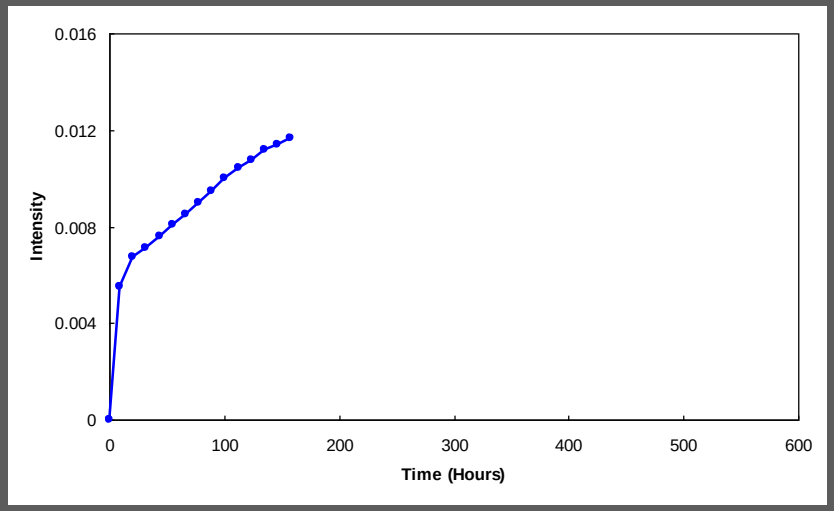
34b-12

146.4 hrs



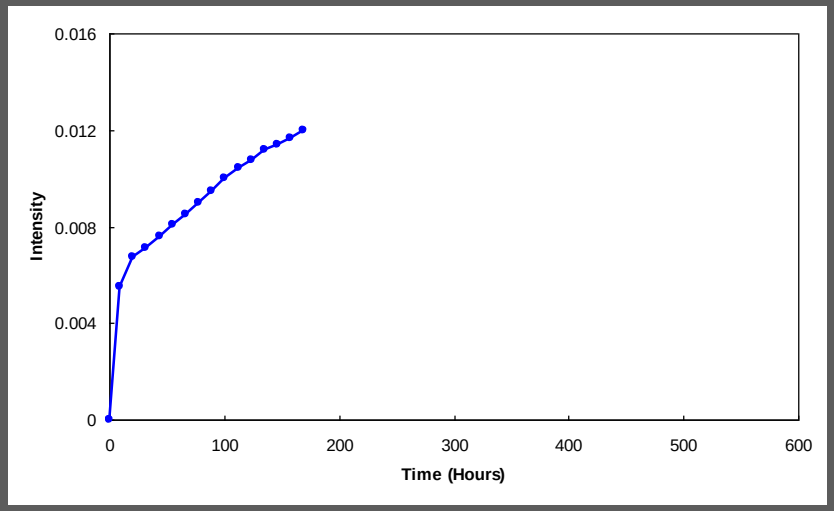
34b-13

157.8 hrs



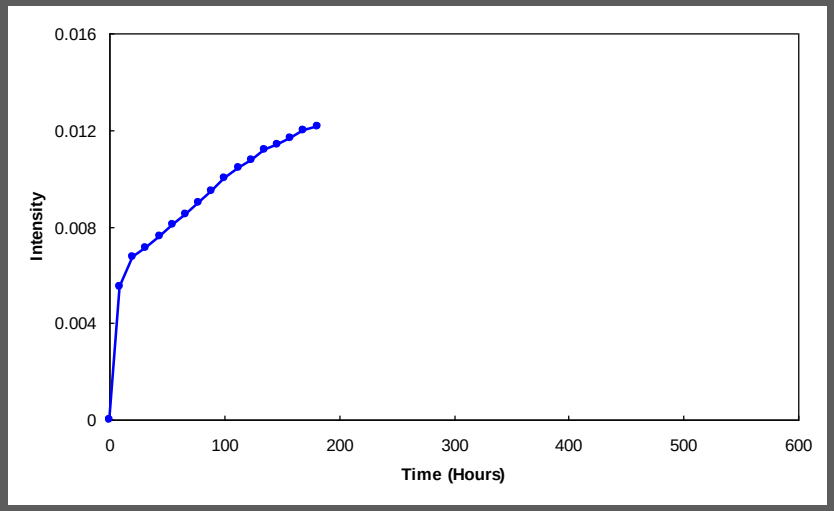
34b-14

169.3 hrs



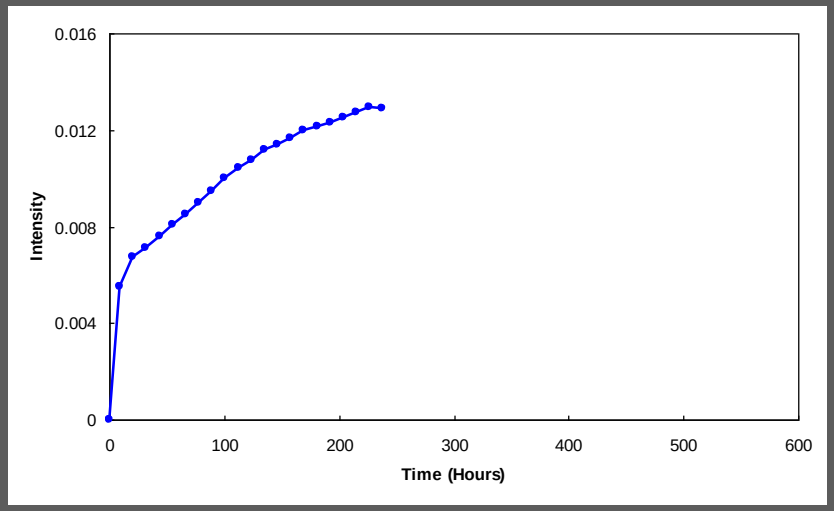
34b-15

180.7 hrs



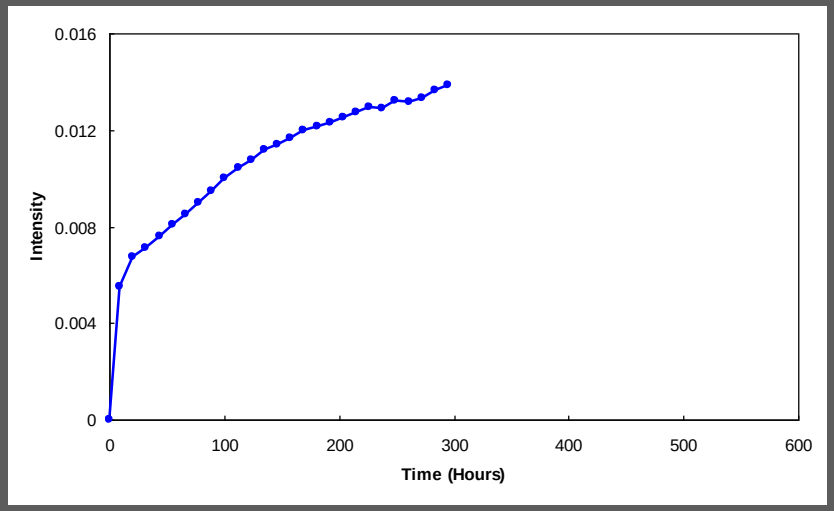
34b-20

237.9 hrs



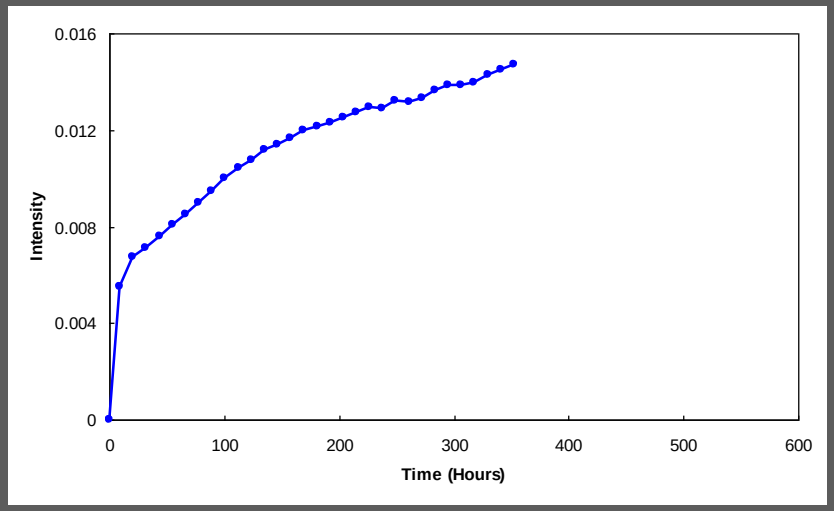
34b-25

295.1 hrs



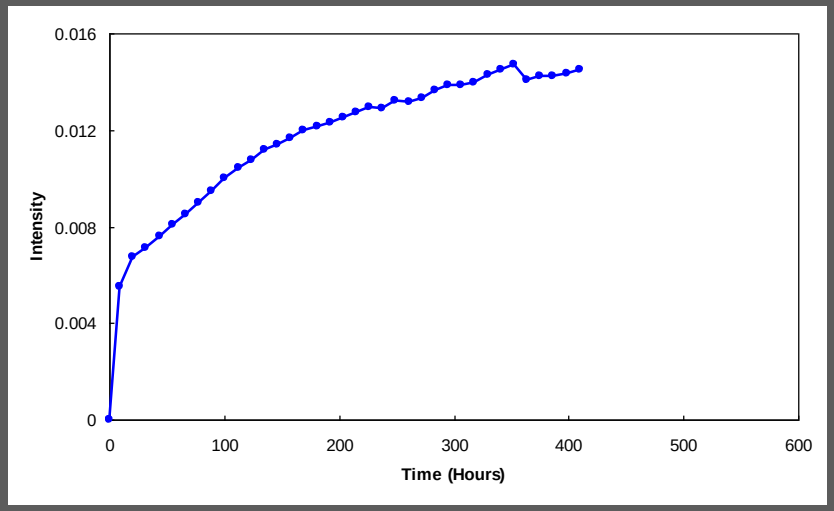
34b-30

352.3 hrs



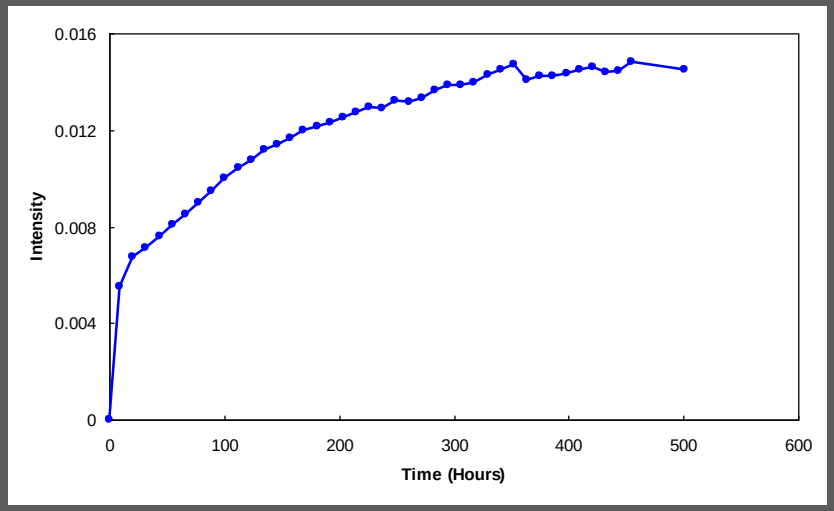
34b-35

409.5 hrs



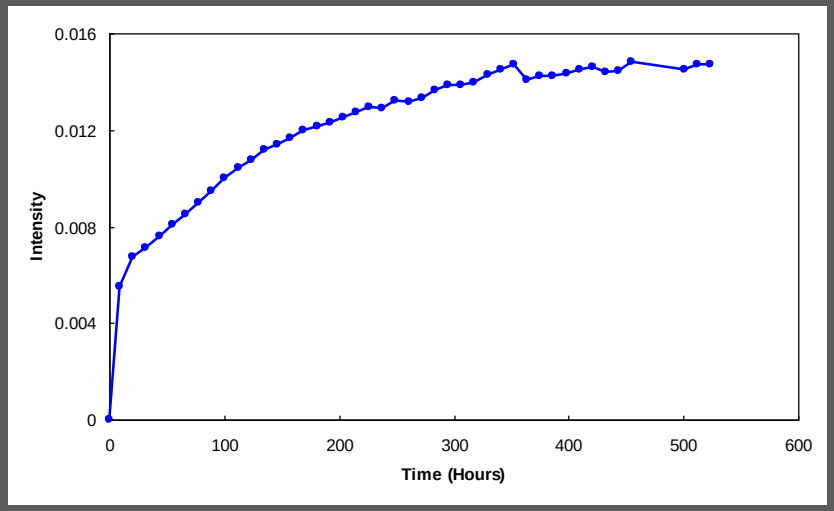
34b-40

501.0 hrs



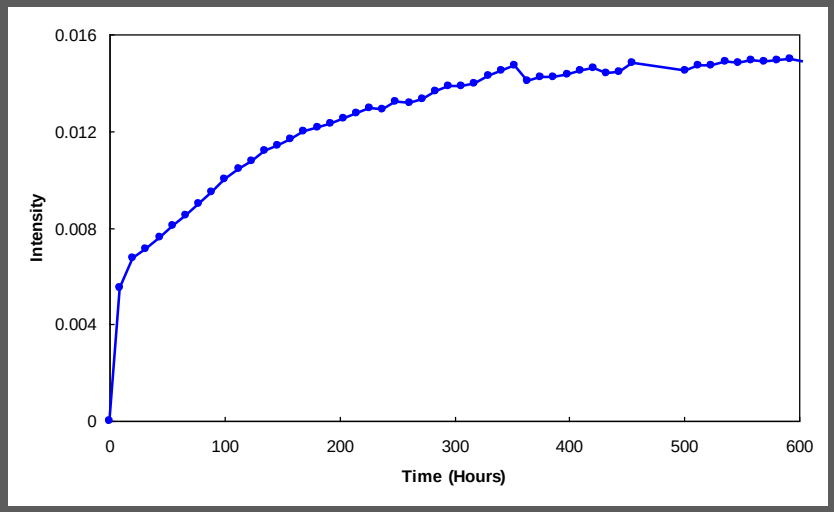
34b-45

523.8 hrs

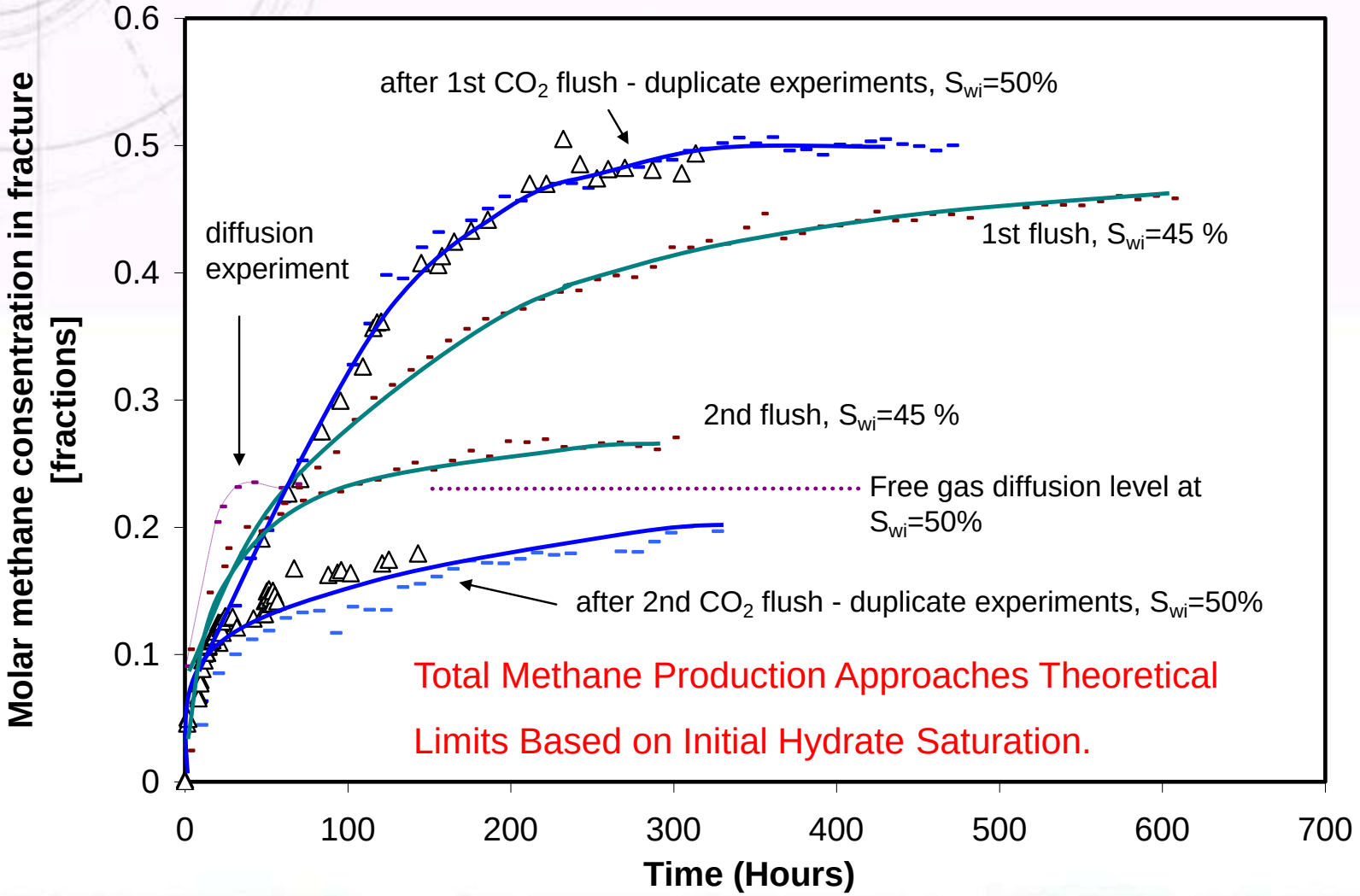


34b-52

603.9 hrs



Methane Production



Scientific Conclusions

- **MRI Provides Unique Dynamic Data of Hydrate Formation and Production Consistent with Conventional Results.**
- **CO_2 Exchange for CH_4 in Hydrates Is Rapid and Efficient.**
- **No Free Water Observed During Exchange Process.**
- **Sufficient Permeability Remains During Hydrate Formation and Subsequent Production.**

Alaska Field Injection Test 2011-2012

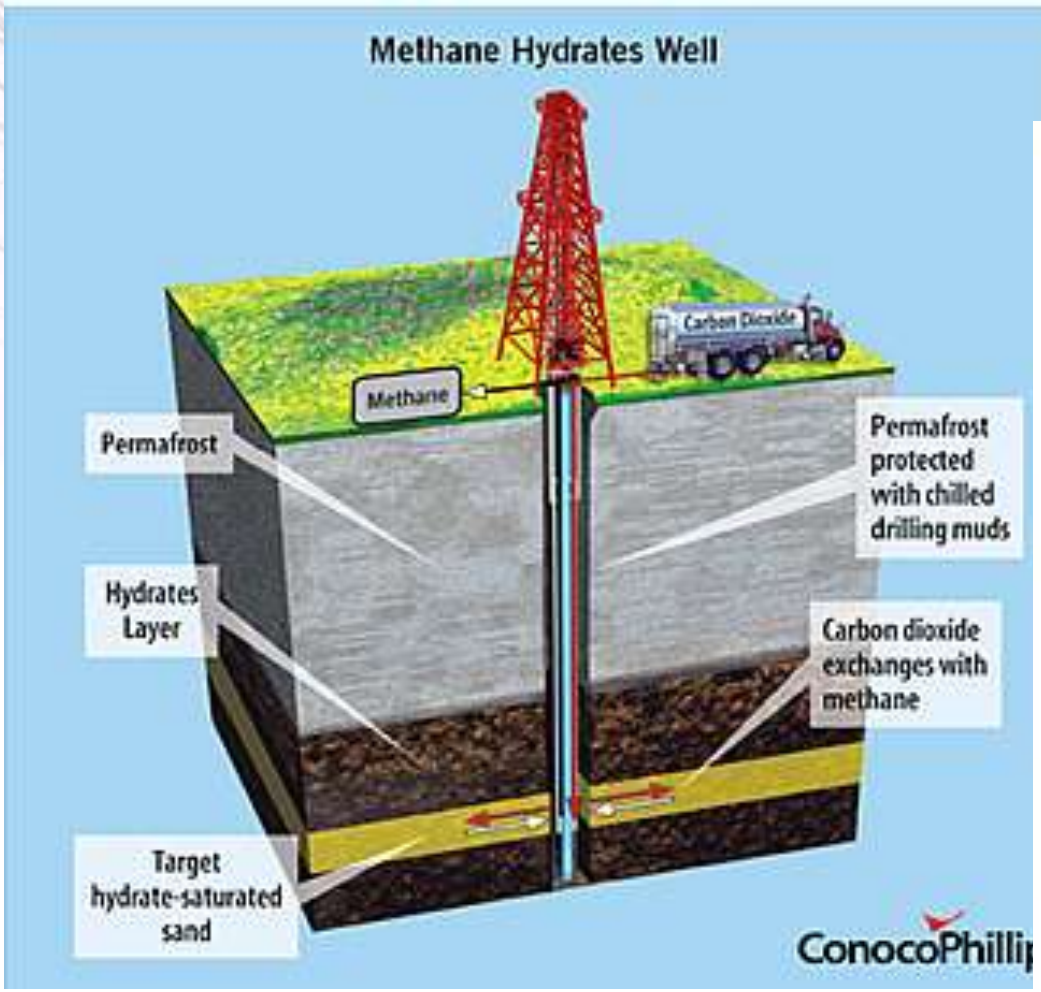
- **ConocoPhillips and JOGMEC**
- **US$ 11.6 mill funding from US DOE, total cost ca. US$30mill**
- **CO_2/N_2 injection**

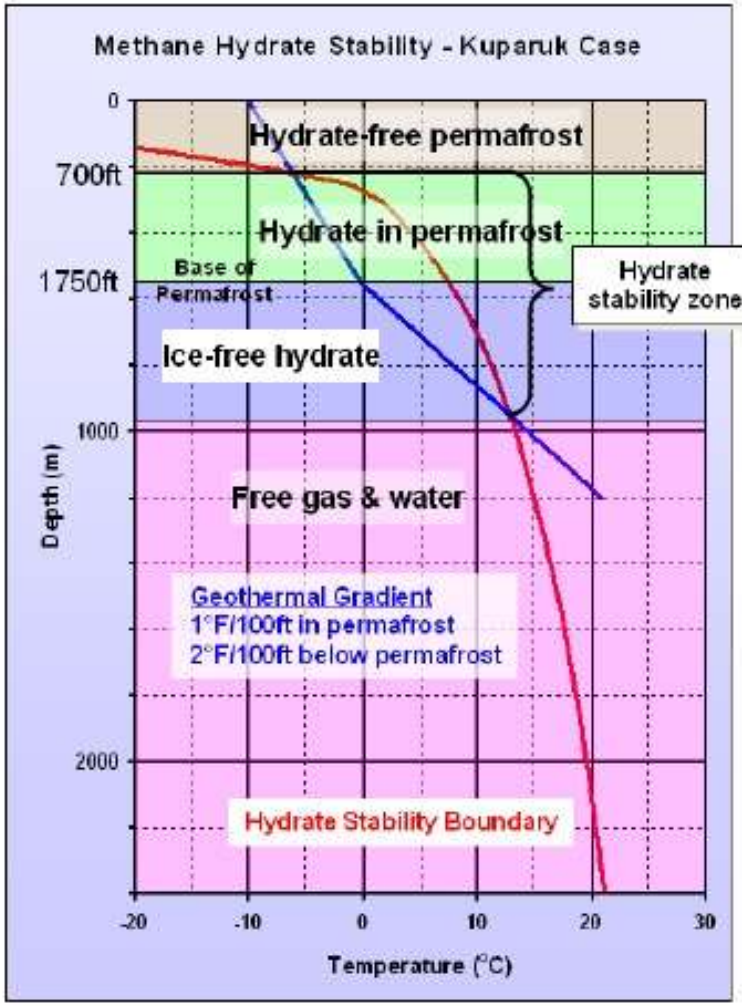
Summary of Field Test (Injection Test)

Schedule:

Apr. 2011:	Drilling test well (Complete)
Nov. 2011:	Finalizing parameters for the field test
Jan.-Apr. 2012:	Field test

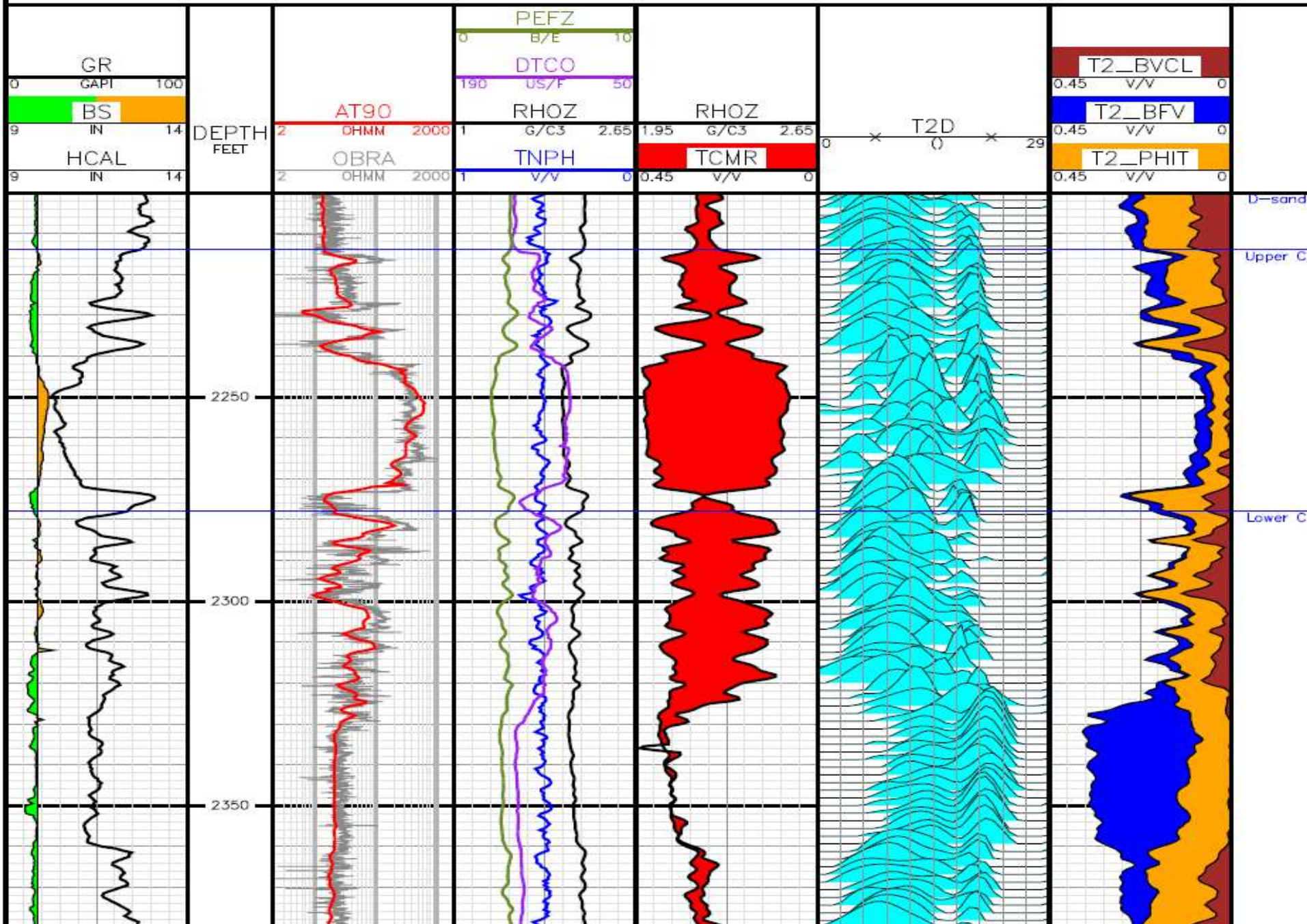
Location：	Prudhoe Bay operating unit in Alaska, USA
Operator：	ConocoPhillips Company (COP), through its wholly owned subsidiary, ConocoPhillips Alaska, Inc.
Investors：	The United States Department of Energy（DOE） JOGMEC; Japan Oil, Gas and Metals National Corp.


Methane Hydrates Well
Carbon Dioxide
Methane
Permafrost
Permafrost protected with chilled drilling muds
Hydrates Layer
Carbon dioxide exchanges with methane
Target hydrate-saturated sand
ConocoPhilli


Methane Hydrate Stability - Kuparuk Case
Hydrate-free permafrost
Hydrate in permafrost
Base of Permafrost
Hydrate stability zone
Ice-free hydrate
Free gas & water
Geothermal Gradient
1°F/100ft in permafrost
2°F/100ft below permafrost
Hydrate Stability Boundary
0
700ft
1750ft
1000
2000
Depth (m)
-20
-10
0
10
20
30
Temperature (°C)

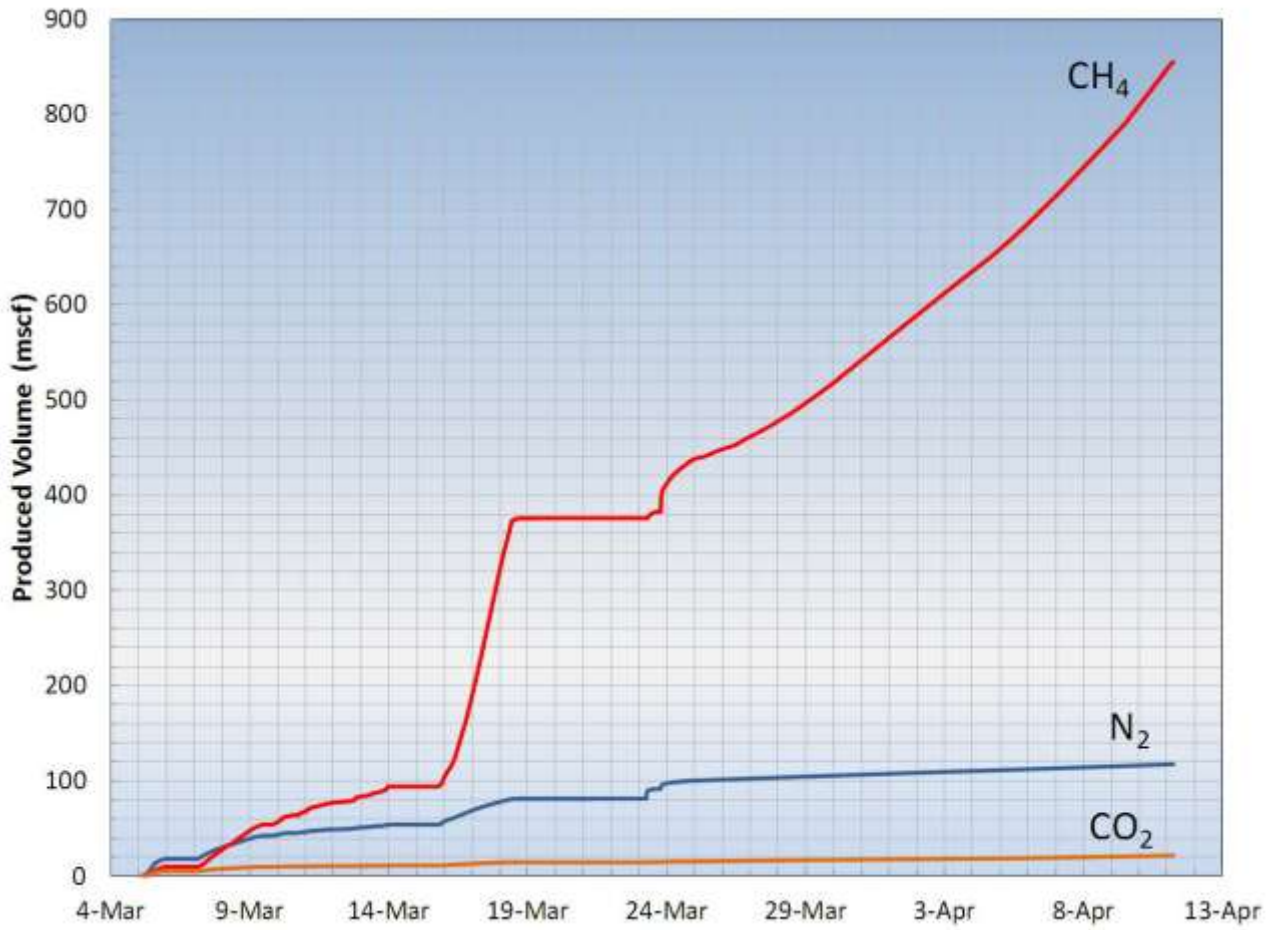
ConocoPhillips

WELL NAME:IGNIK_SIKUMI_#1




Iġnik Sikumi #1
Prudhoe Bay Unit L-pad

Gas Production from the Field Test



Ignik Sikumi #1 Flowback/Drawdown: Gas composition

Schoderbek, 2012

Thank You!