CO2 Injection for Methane Production from Hydrate Reservoirs

by

A. Graue, G. Ersland and S. Almenningen

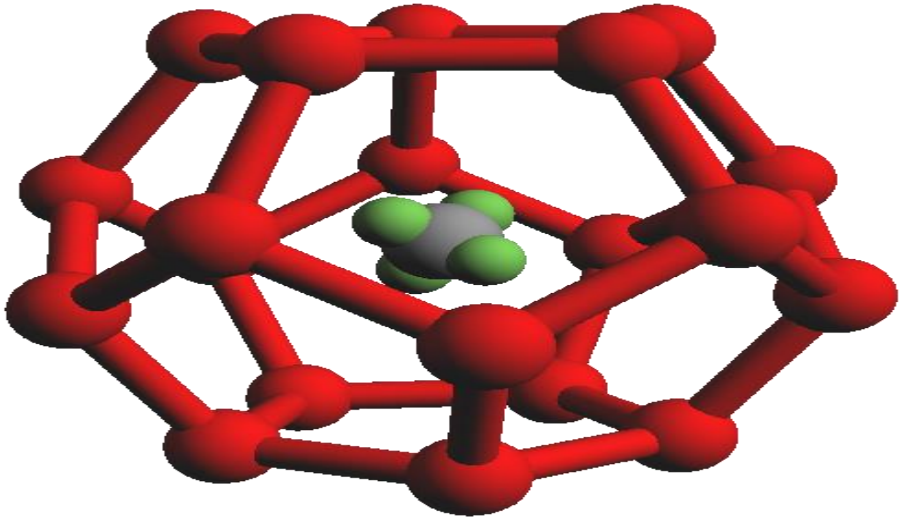
Dept. of Physics and Technology

University of Bergen, NORWAY

2nd Biennial CO2 for EOR as CCUS Conf., Houston, TX, Oct. 4-6th, 2015

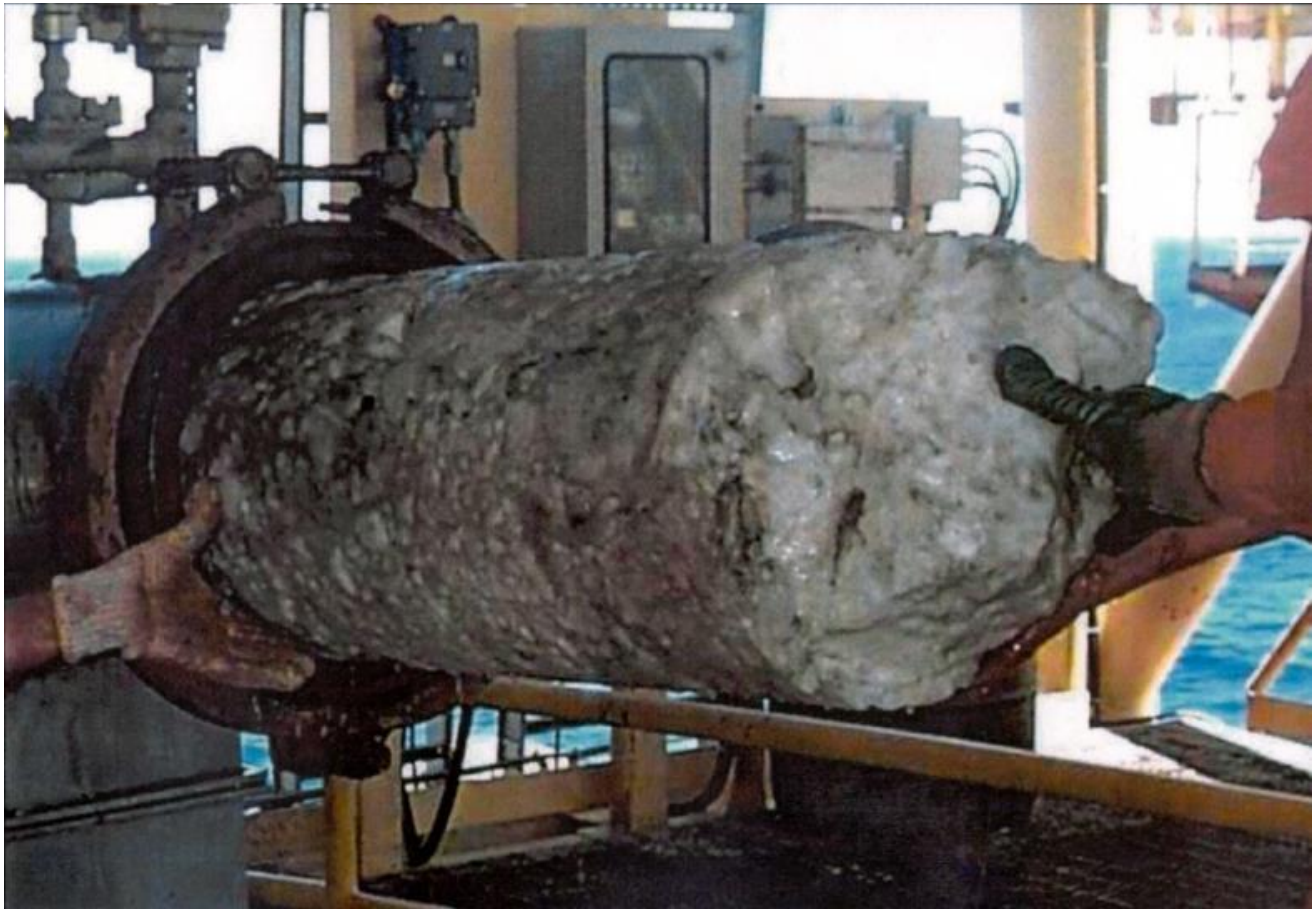
GAS HYDRATES

- Solid state of gas and water where the water molecules form a cavity that encapsulates the guest molecule.



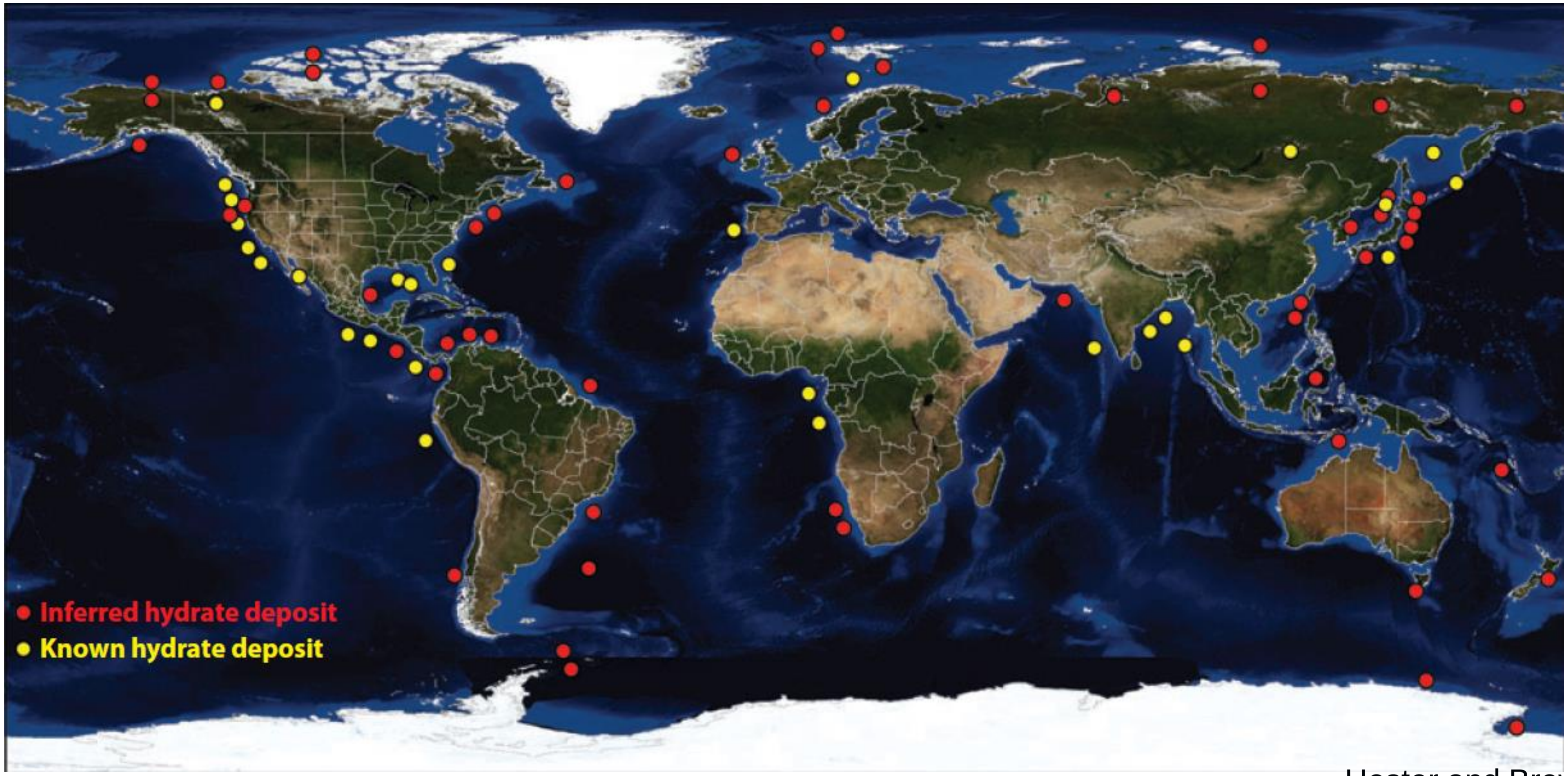
Why are hydrates of interest?

- Initial interest as a curiosity
- Plugging of production and transportation pipelines



Renewed interest

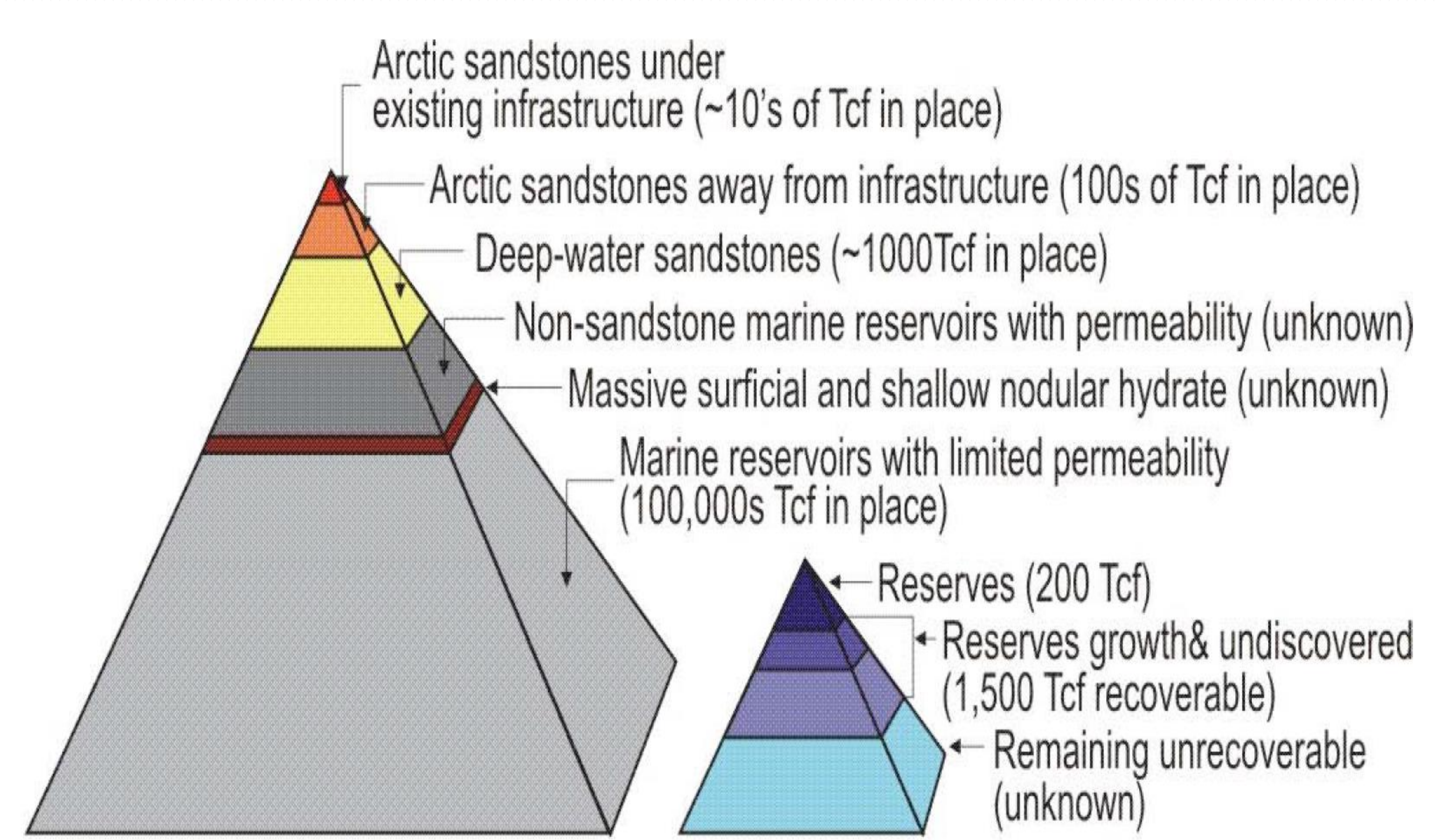
- Significant amount of energy
  - Permafrost regions
  - Marine environments (high water column)



Hester and Brewer, 2009

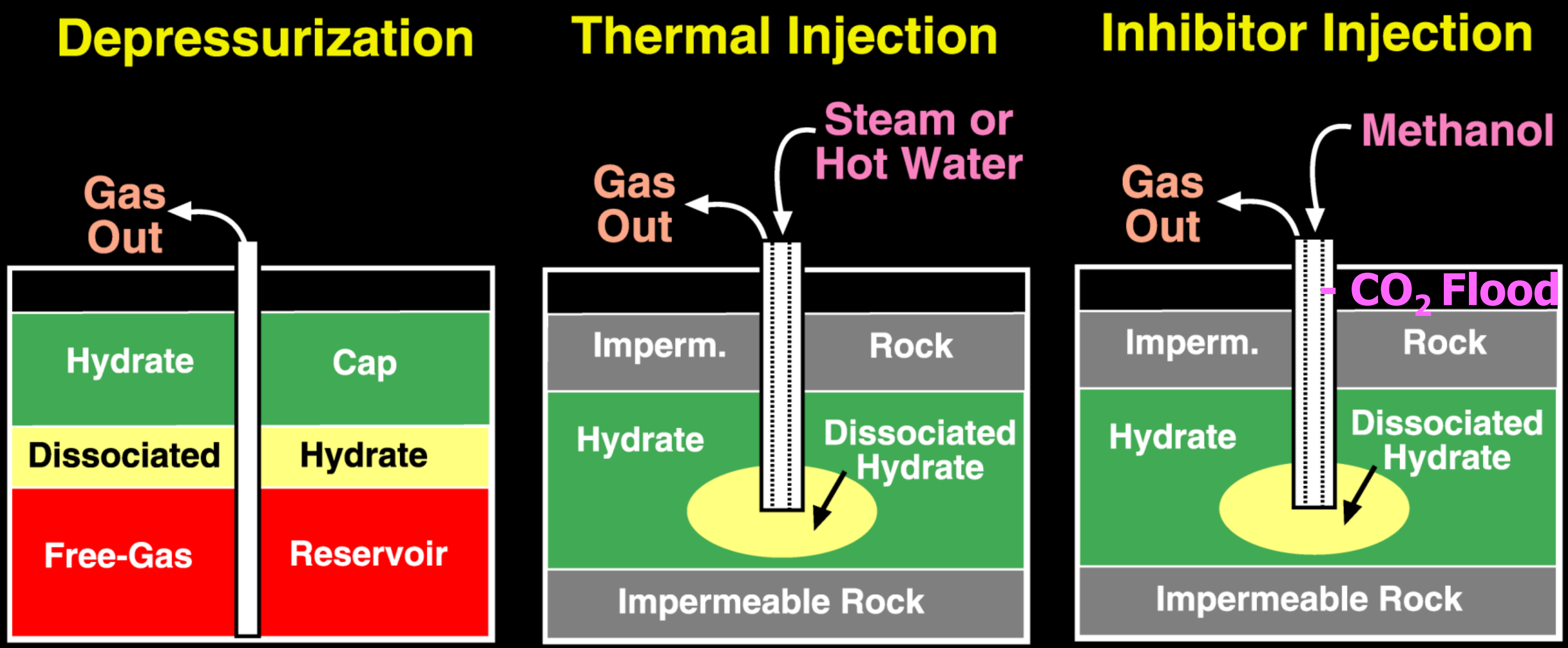
Hydrate as Energy Resource

Ref.: Fire in the Ice, U.S. Department of Energy • Office of Fossil Energy • National Energy Technology Laboratory



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

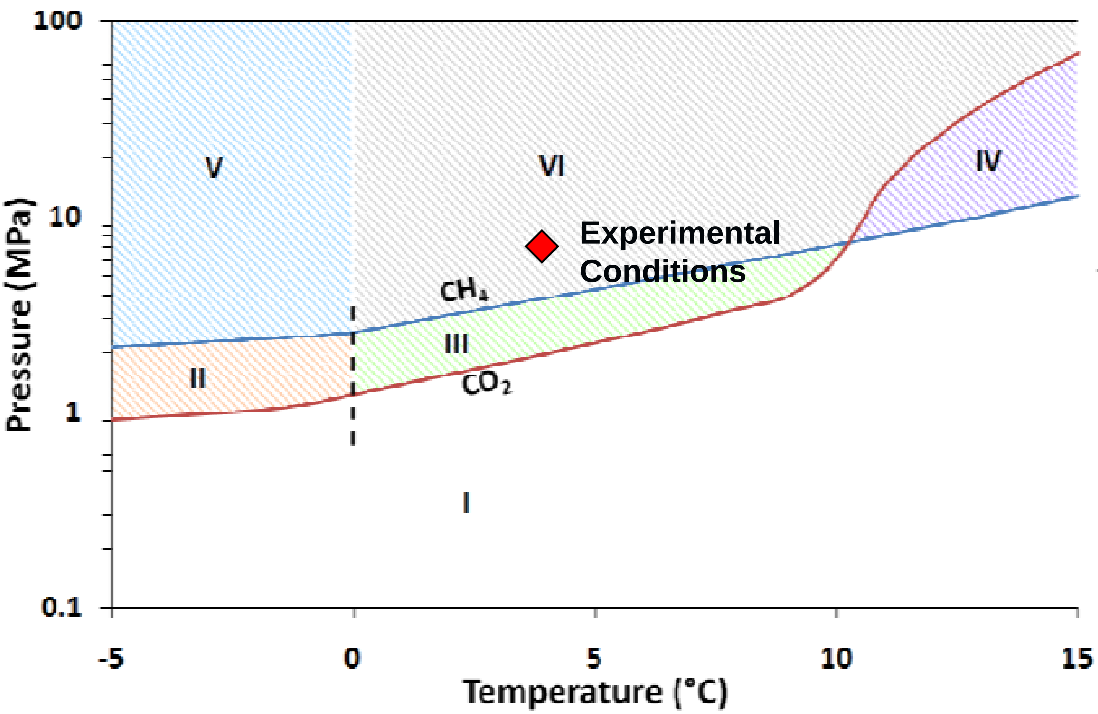
Gas Hydrate Production Methods



Modified from "GAS HYDRATES OF NORTHERN ALASKA", January 2005
Evaluation of Alaska North Slope Gas Hydrate Energy Resources: A Cooperative Energy Resource Assessment Project
US Bureau of Land Management, US Geological Survey, & State of Alaska Division of Geological and Geophysical Surveys
Bob Fisk, USBLM, Anchorage, Alaska, Tim Collett, USGS, Denver, Colorado & Jim Clough, DGGS, Fairbanks, Alaska

CH_4 PRODUCTION INDUCED BY CO_2 INJECTION

- Provides thermodynamically more stable gas hydrate than CH_4

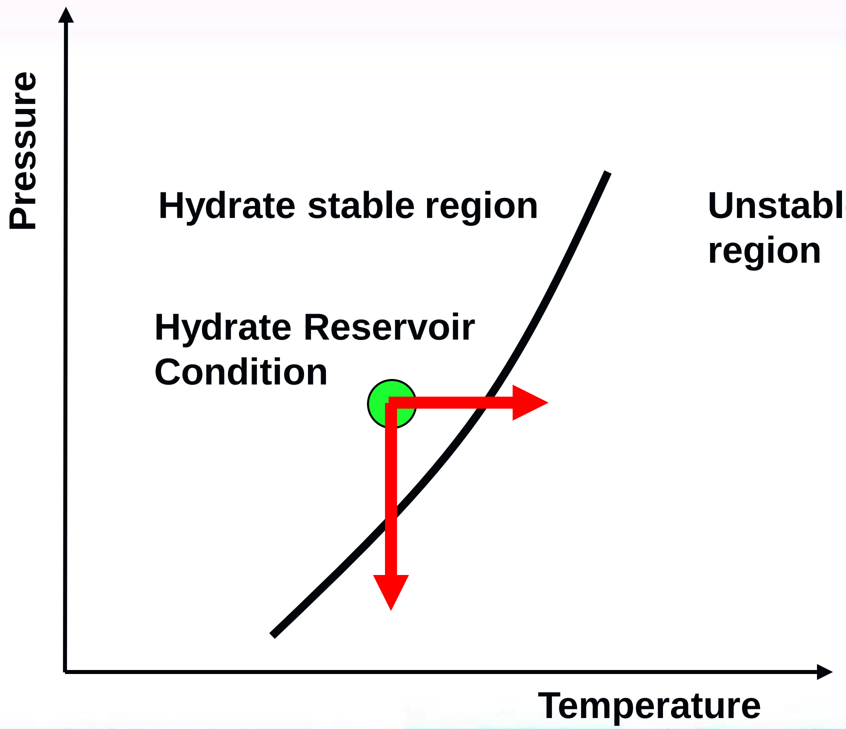


PT-Area	Water and Hydrate Phases
I	No hydrates
II	I-H_{CO2}
III	L_W-H_{CO2}
IV	L_W-H_{CH4}
V	I-H_{CO2}-H_{CH4}
VI	L_W-H_{CO2}-H_{CH4}

Husebø, 2008

GAS HYDRATE PRODUCTION METHODS

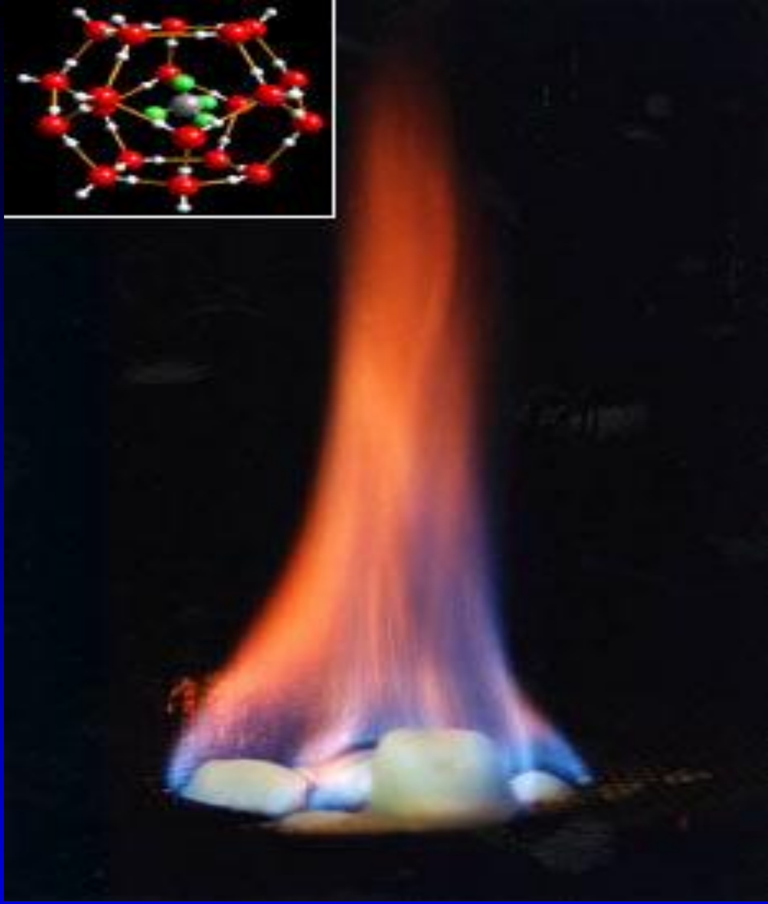
- **Move the gas hydrate outside its stability region**
  - **Depressurization**
  - **Thermal stimulation**
  - **Hydrate inhibitors**
- **CO2 exchange**



CO2 Exchange: Project Motivation

- The amount of energy bound in hydrates may be more than twice the world's total energy resources in conventional hydrocarbon reservoirs; i.e. oil-, gas- and coal reserves
- Simultaneous CO_2 Sequestration
- Win-win situation for gas production
- Need no hydrate melting or heat stimulation
- Spontaneous process
- No associated water production
- Formation integrity

CO2 storage in hydrates with associated methane gas production



Challenge:

Determine exchange mechanisms during potential sequestration of CO_2 to produce methane from hydrates

Three component Phase Field Theory

$$F = \int d\underline{r} \left\{ \frac{\varepsilon^2 T}{2} (\nabla \phi)^2 + \sum_{i,j=1}^{3} \frac{\varepsilon_{i,j}{}^2 T}{4} \left(c_i \nabla c_j - c_j \nabla c_i \right)^2 + f_{bulk}(\phi, c_1, c_2, c_3, T) \right\}$$

$$f_{bulk} = wTg(\phi) + [1 - p(\phi)] f_S(c_1, c_2, c_3, T) + p(\phi) f_L(c_1, c_2, c_3, T)$$

$$\dot{\phi} = -M_\phi \frac{\delta F}{\delta c} + \zeta_\phi$$

$$\sum_{i=1}^{3} c_i = 1$$

$$\dot{c}_i = \nabla M_{ci}(c_1, c_2, c_3) \nabla \left(\frac{\delta F}{\delta c_i} - \zeta_i \right)$$

Parameters ε and w can be fixed from the interface thickness and interface free energy. ε ij set equal to ε

CO_2 Storage in Hydrate Reservoirs with Associated Spontaneous Natural Gas Production

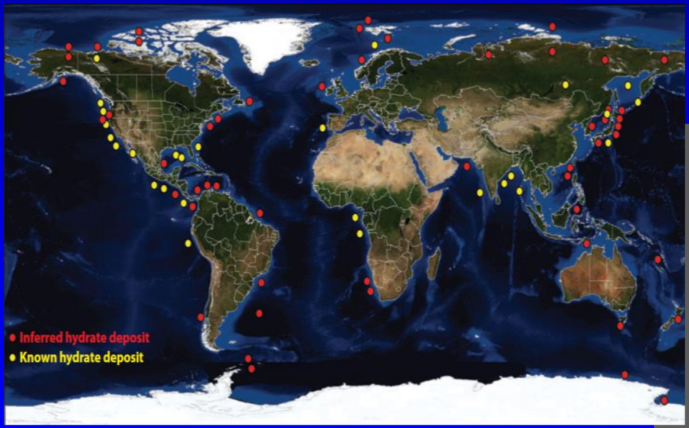
Arne Graue and Bjørn Kvamme, Dept. of Physics, University of Bergen, NORWAY

Funding: ConocoPhillips, Statoil and The Research Council of Norway

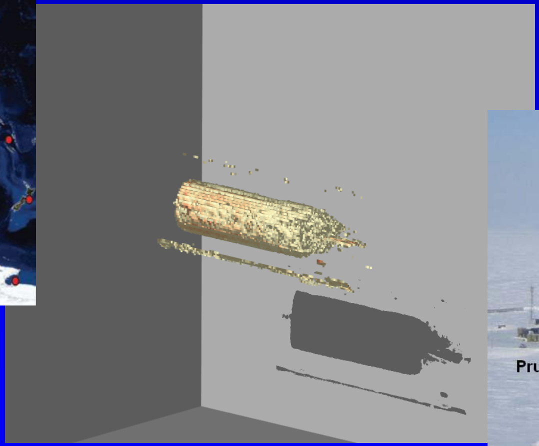
Objectives:

Experimentally and theorethically determine spontaneous methane production when hydrate is exposed to CO2; with the purpose of CO2 sequestration.

Methane hydrate reservoirs



***In-Situ* imaging (MRI) of hydrate formation**



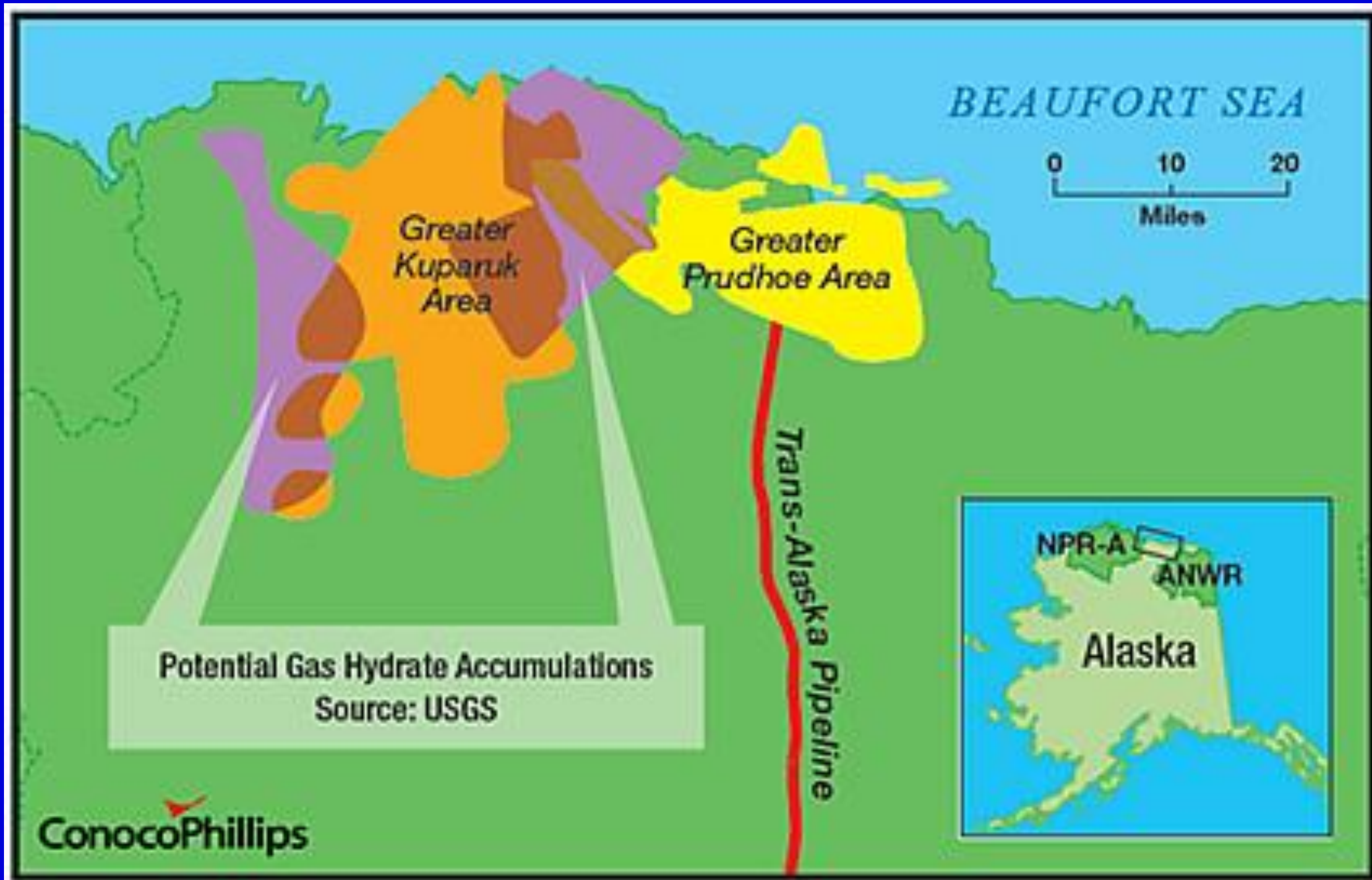
Methane production by CO2 injection in field test in Alaska 2012

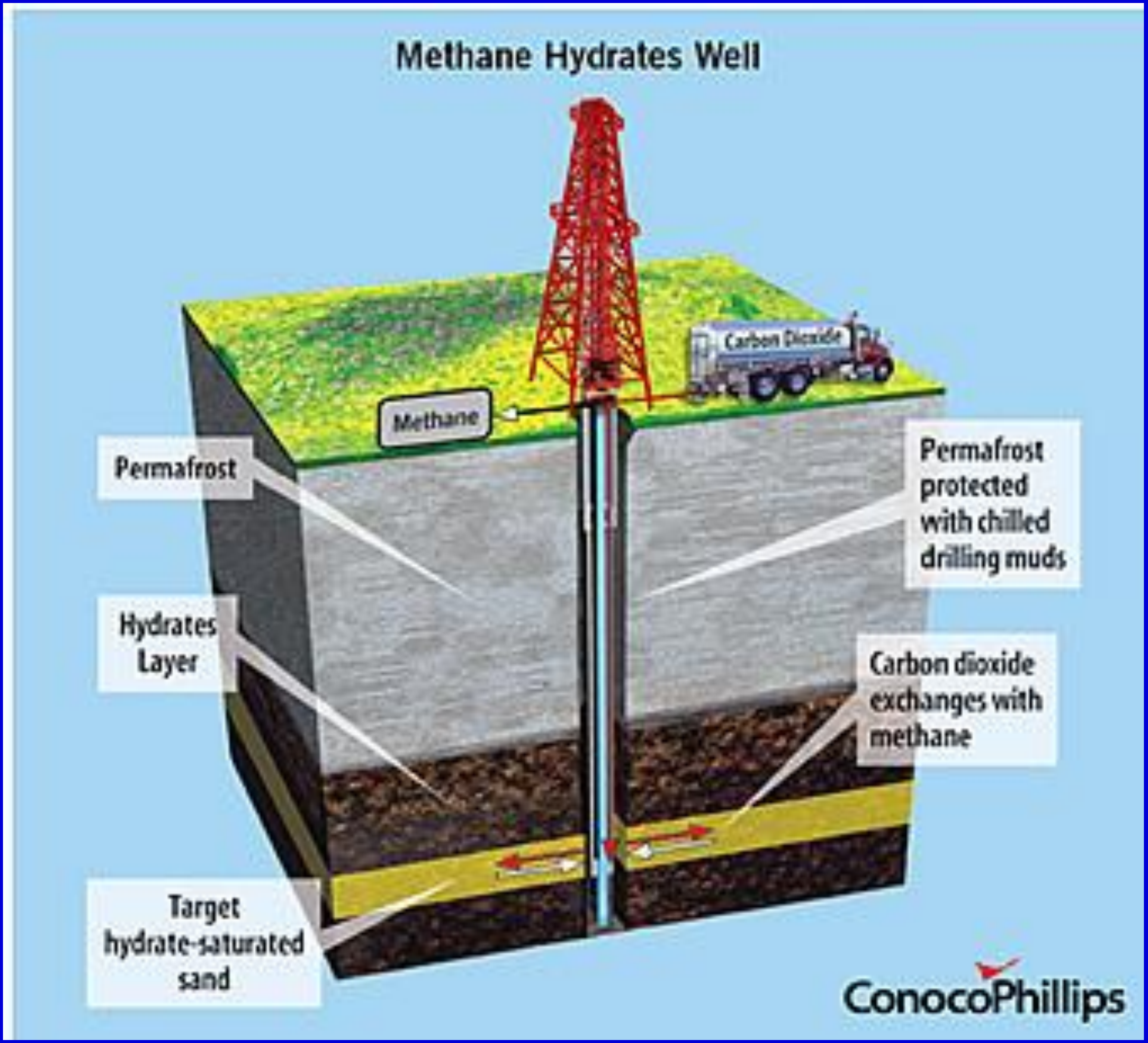
Summary of Field Test (Injection Test)

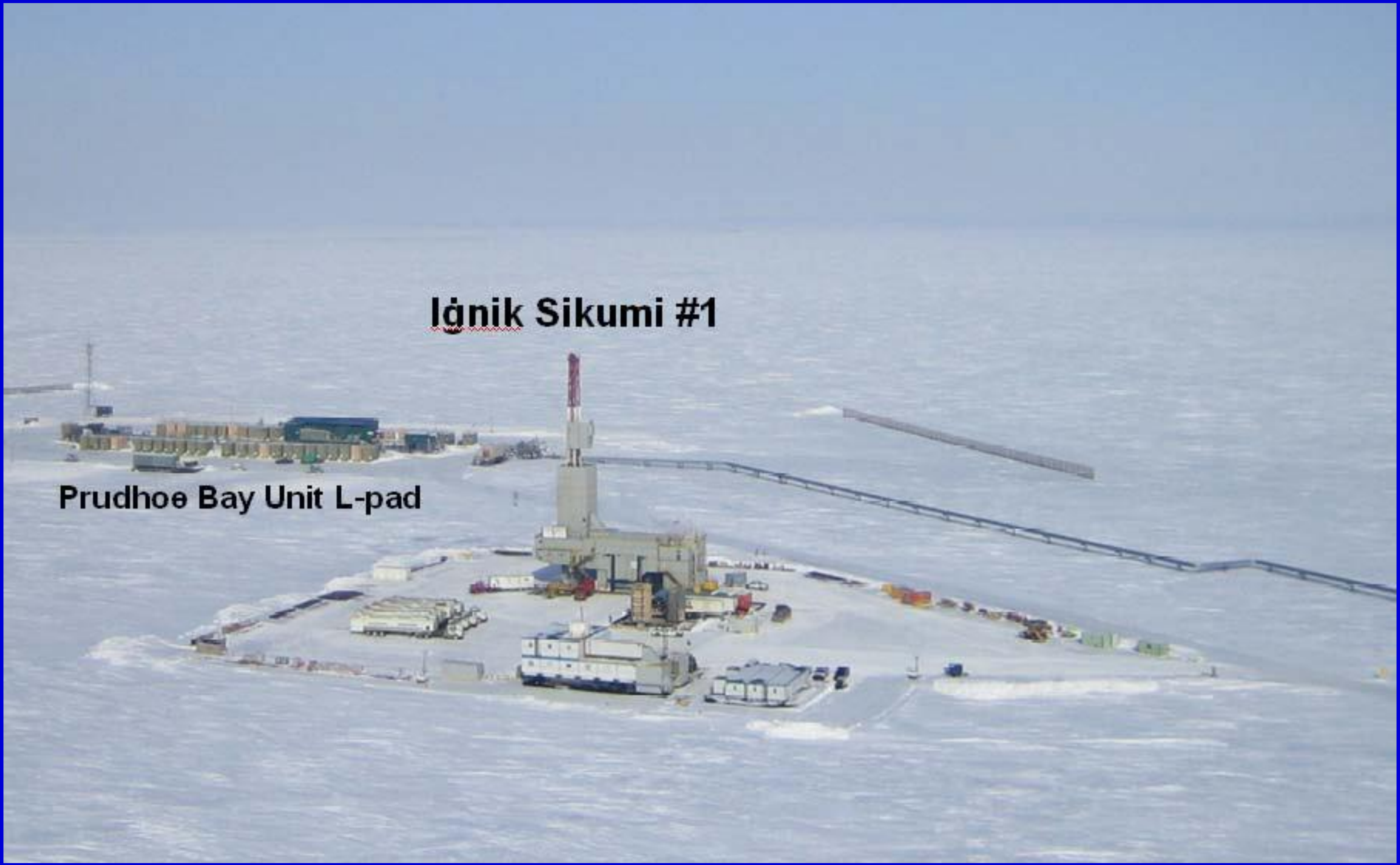
Schedule:

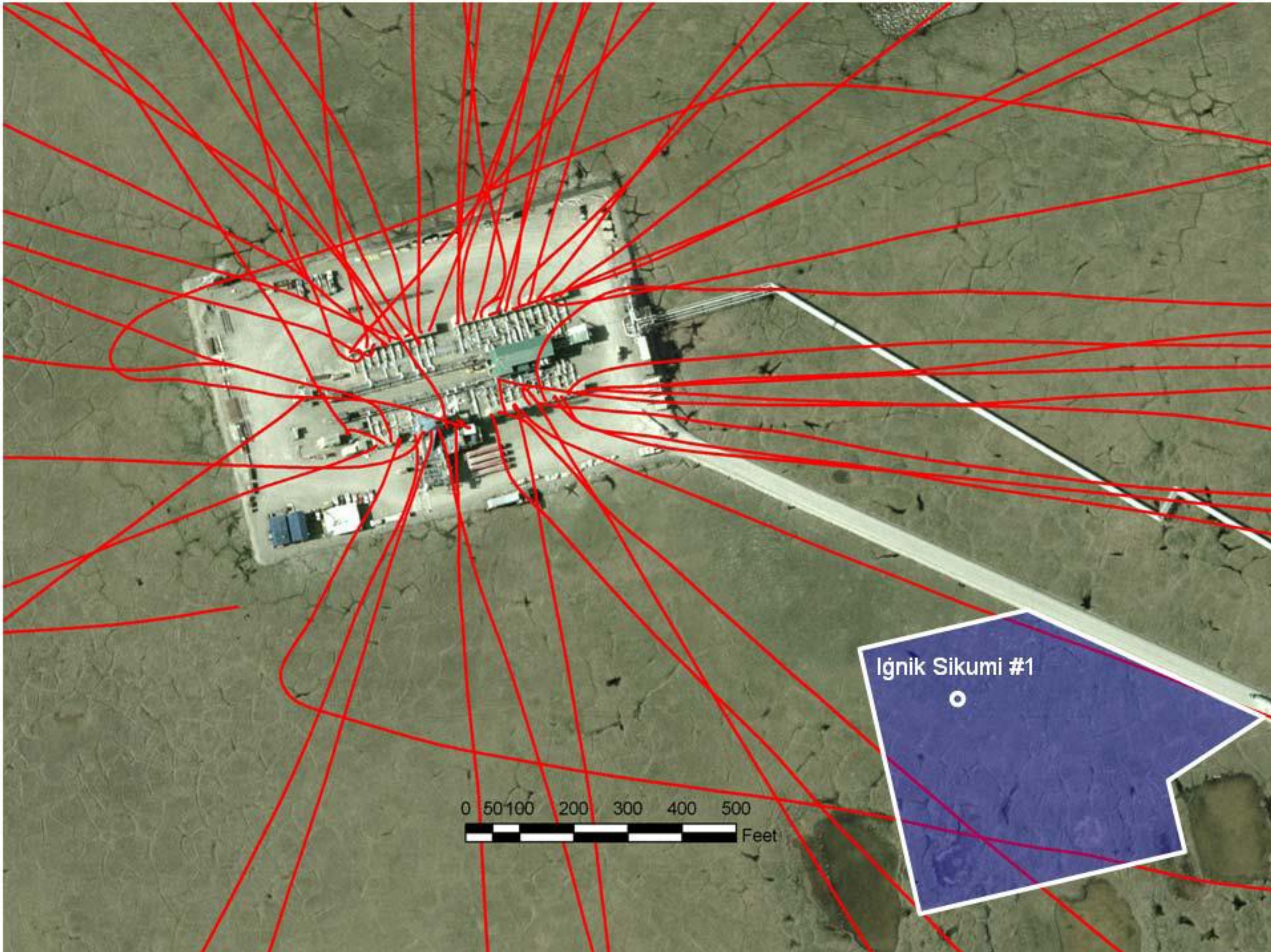
Apr. 2011: **Drilling test well (Complete)**
Nov. 2011: **Finalizing parameters for the field test**
Jan.-Apr. 2012: **Field test**

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.

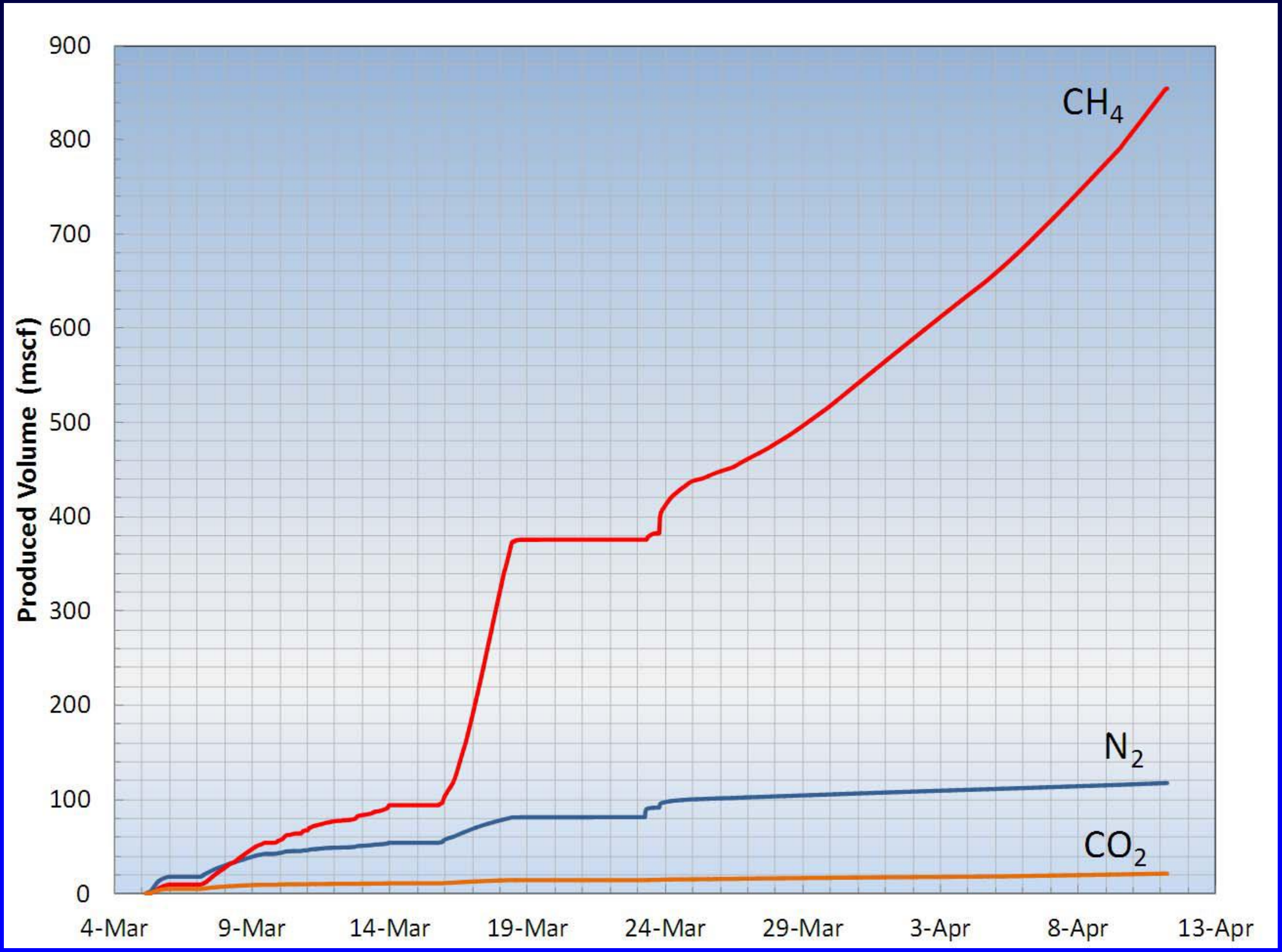

BEAUFORT SEA
0 10 20
Miles
Greater Kuparuk Area
Greater Prudhoe Area
Trans-Alaska Pipeline
Potential Gas Hydrate Accumulations
Source: USGS
NPR-A
ANWR
Alaska
ConocoPhillips


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


Iġnik Sikumi #1
Prudhoe Bay Unit L-pad


Iġnik Sikumi #1
0 50 100 200 300 400 500
Feet

Gas Production from the Field Test



Iġnik Sikumi #1 Flowback/Drawdown: Gas composition

STATUS

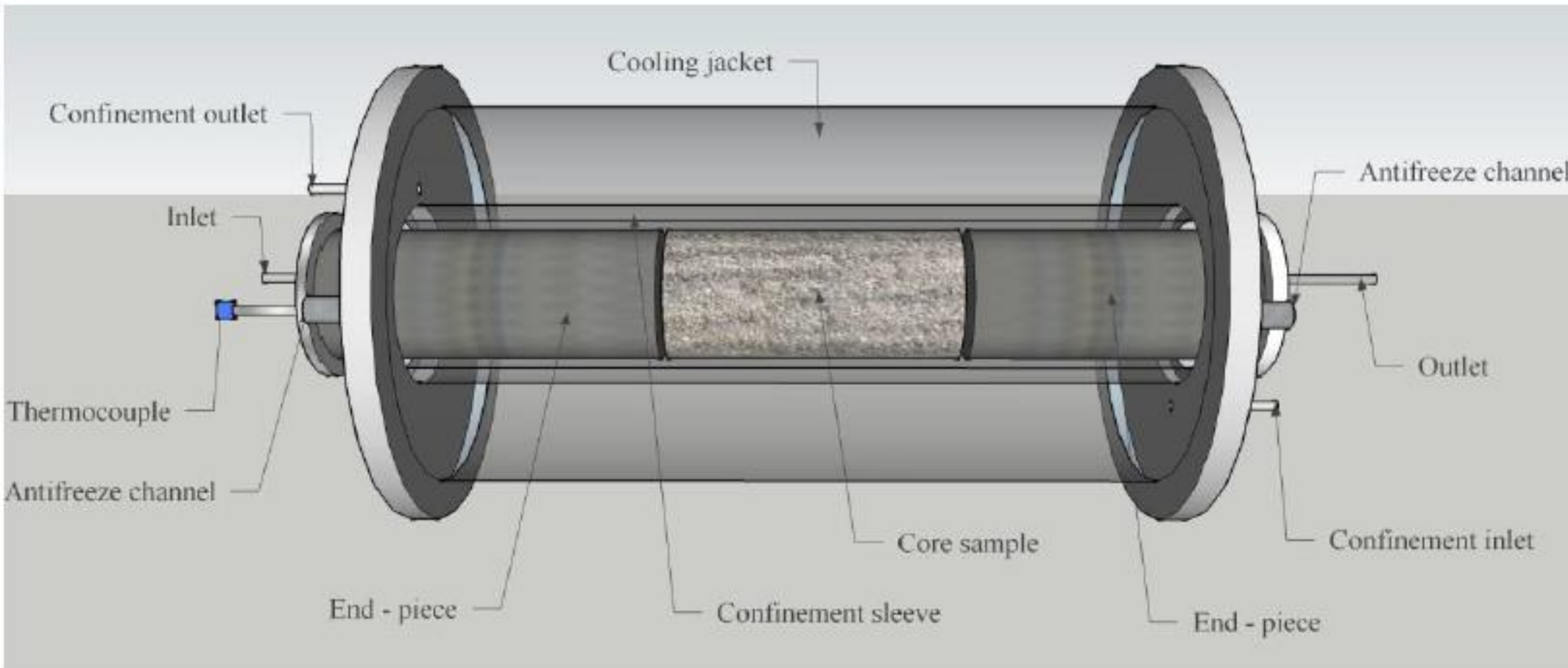
Alaska Field Injection Test 2011-2012

- **ConocoPhillips and JOGMEC**
- **US$ 11.6 mill funding from US DOE, total cost ca. US$30mill**
- **CO2 injection**

Core properties

- Bentheim sandstone cores
  - Porosity ~22%
  - Permeability ~1.1 Darcy
  - Grain density ~2.65 g/cm^3
  - Mineralogy ~95% quartz

Experimental design



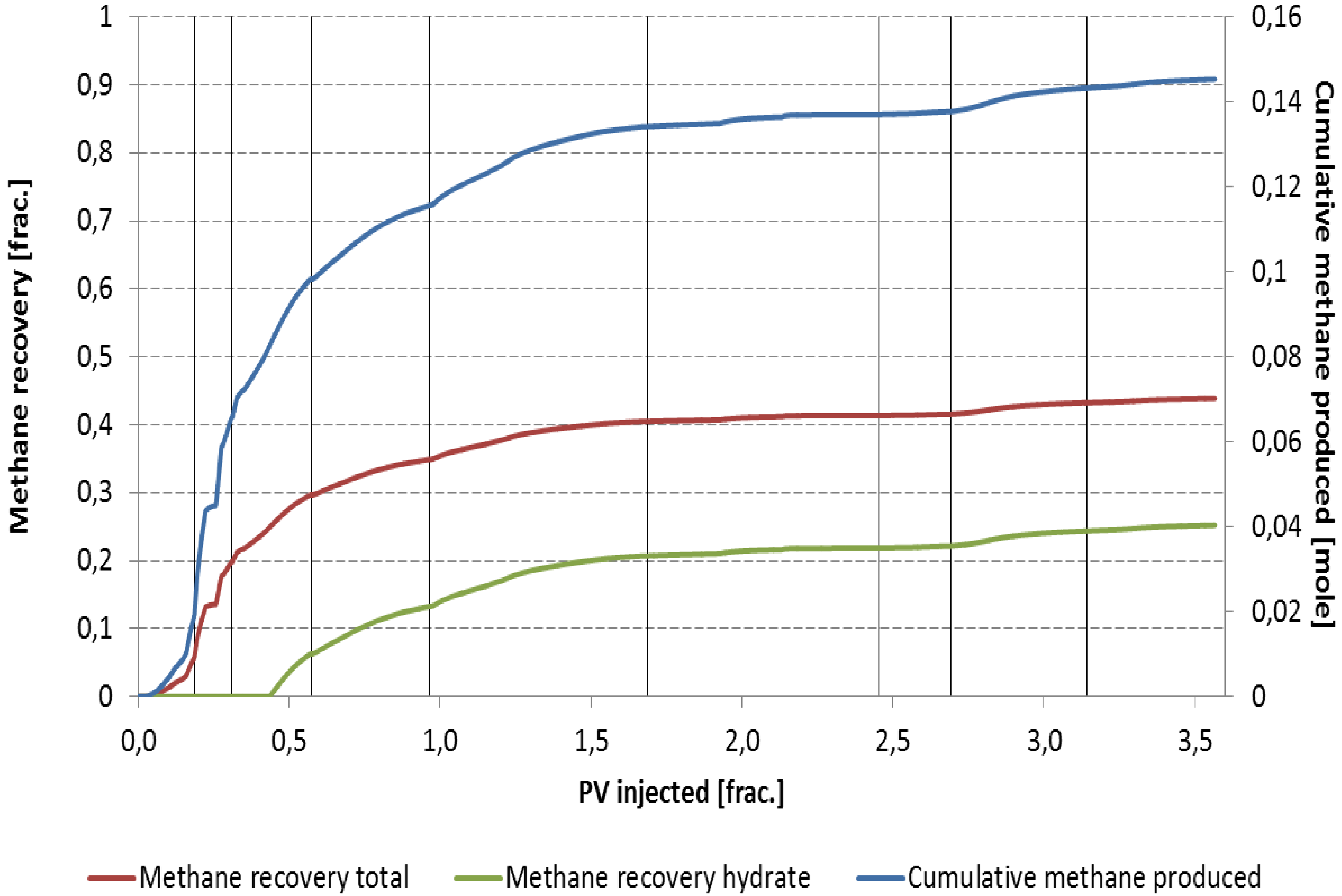
Hossainpour (2013)

Hydrate formation

- Pressure: 83 bar
- Temperature: 4.0 °C
- Initial brine salinity: 3.5 wt% (NaCl)
- Initial brine saturation: 0.69 [frac.]

- Final brine saturation: 0.31 [frac.]
- Final gas saturation: 0.20 [frac.]
- Final hydrate saturation: 0.49 [frac.]

CH_4-CO_2 exchange



Conclusion

- A binary mixture of 60% N_2 and 40% CO_2 [mole percent] was successfully injected into a hydrate-filled whole core containing excess water. The initial rate of methane recovery from hydrates was high but had a rapid decline.

How will the unconventional gas boom affect prices in other markets?

WORLD ENERGY OUTLOOK

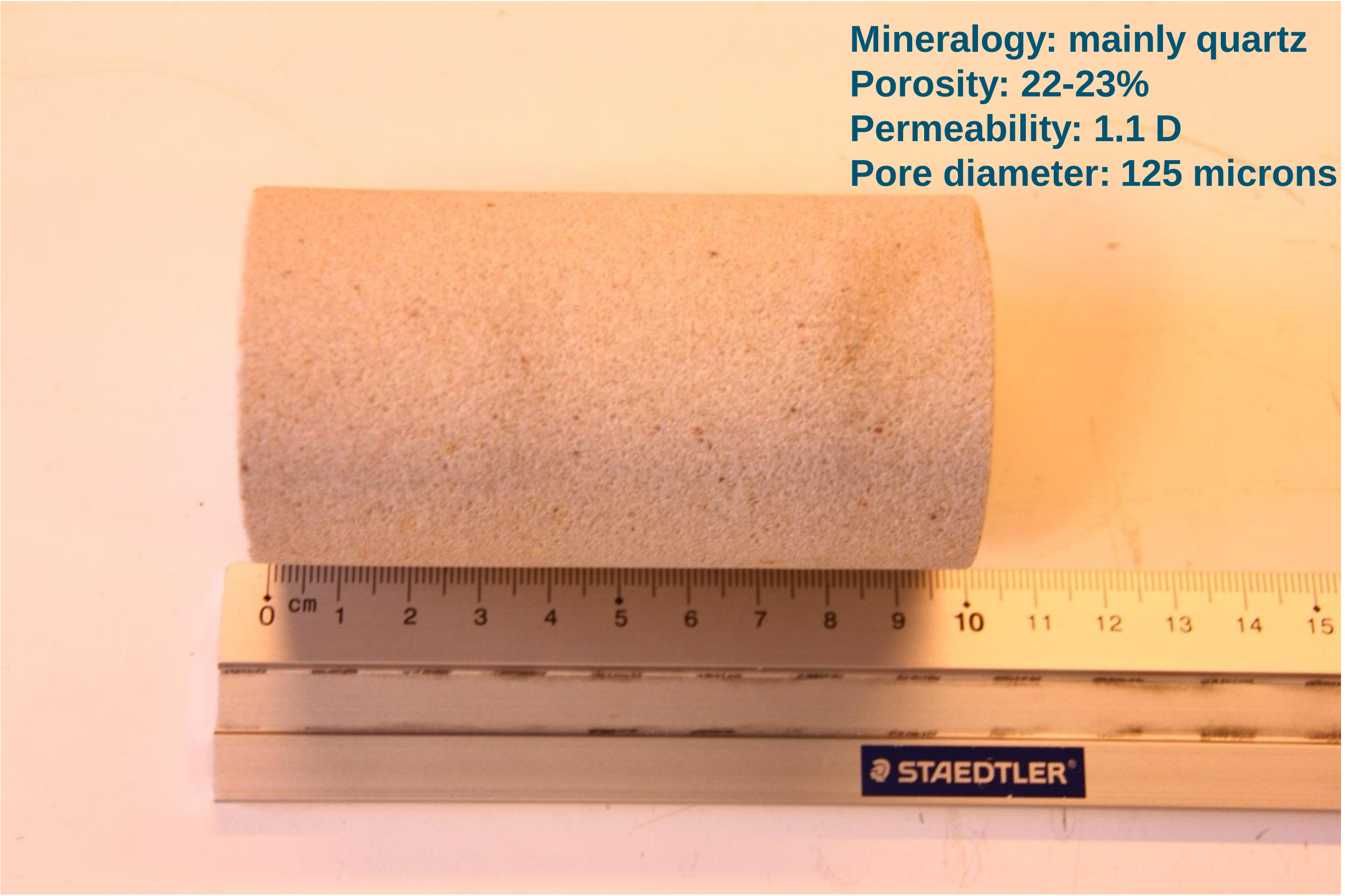
Average natural gas prices by region, May 2012

Unconventional gas boom will spur a degree of convergence in global prices by putting pressure on oil-price indexation of gas contracts in Europe & Asia

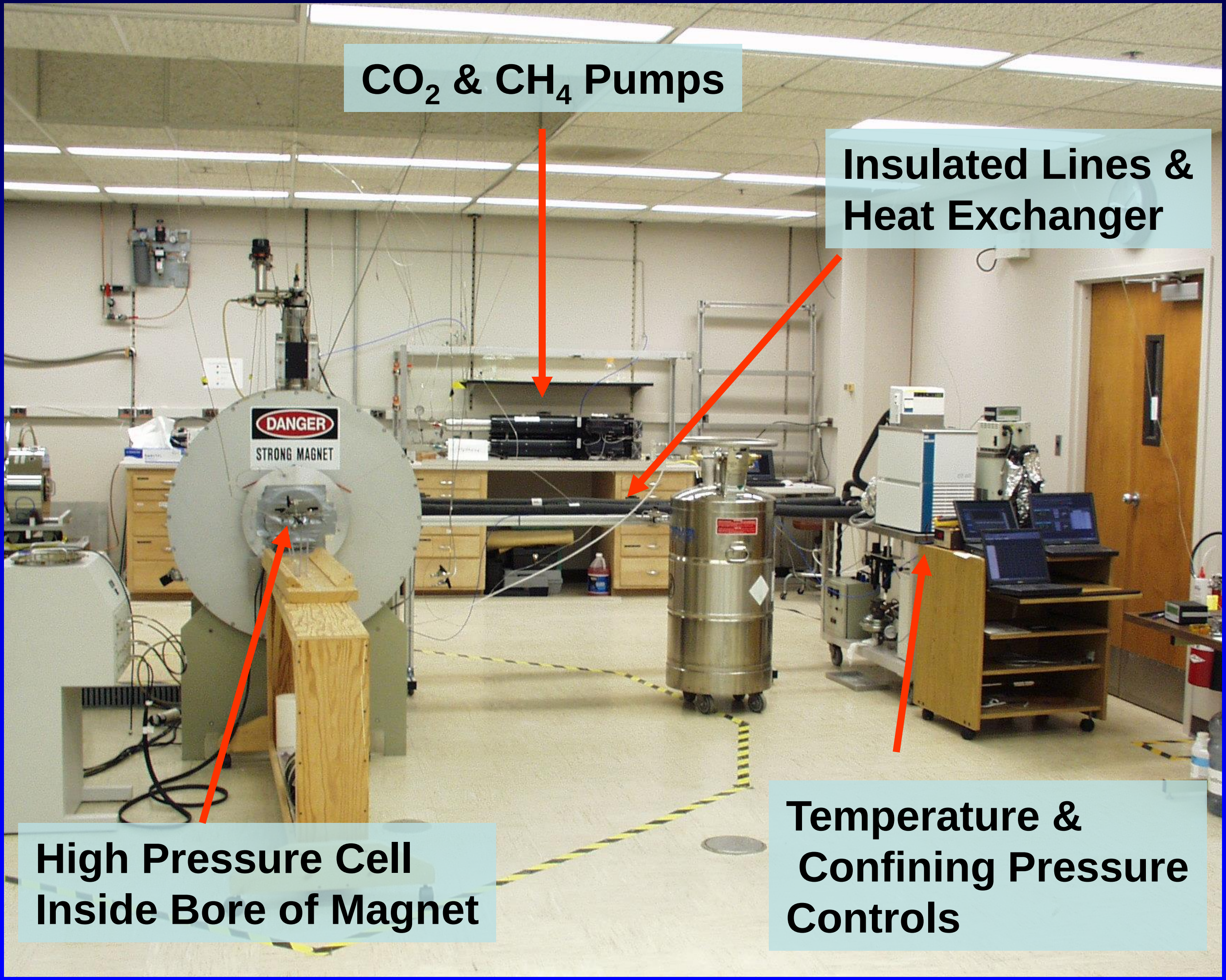
Thank you!

CONDITIONS OF A HYDRATE RESERVOIR

- Hydrate reservoirs are often found in porous media
  - Sedimentary rock



Experimental Setup

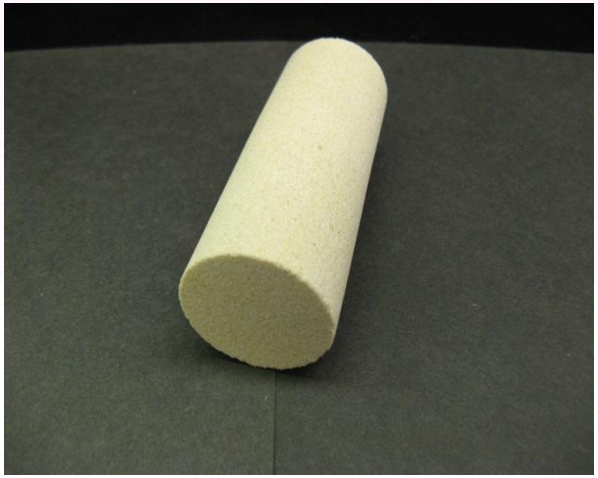


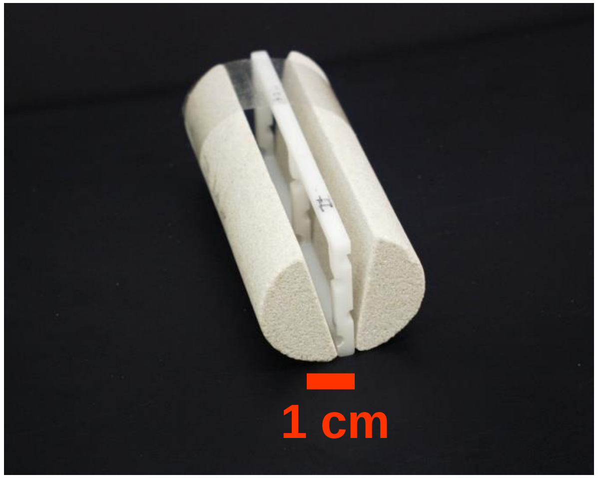
Core Sample Design

Bentheim Sandstone

20-25% porosity, ~1.1 D Perm

- Whole Core
- Longitudinal Cut With Machined Spacer to Simulate Open Fracture.

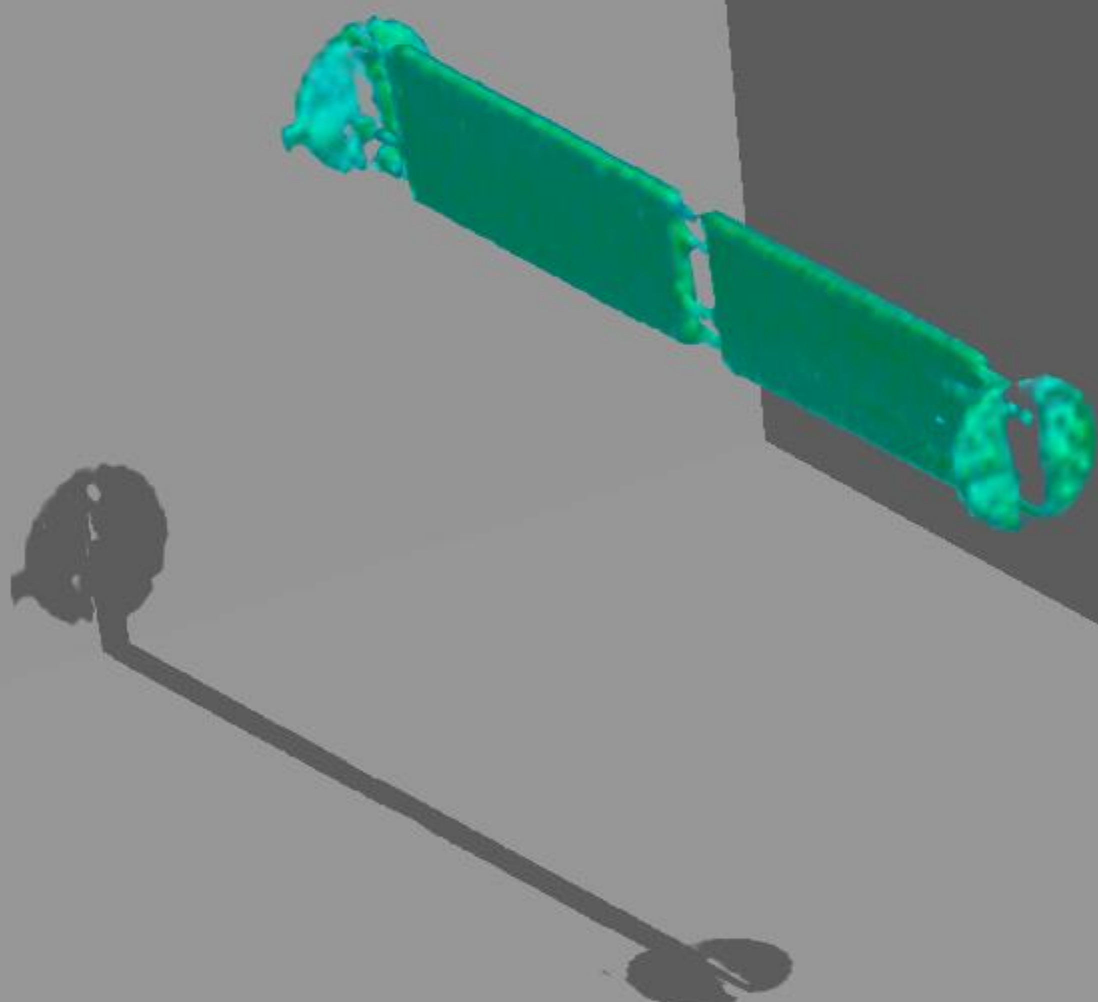




33-03

0.0 hrs

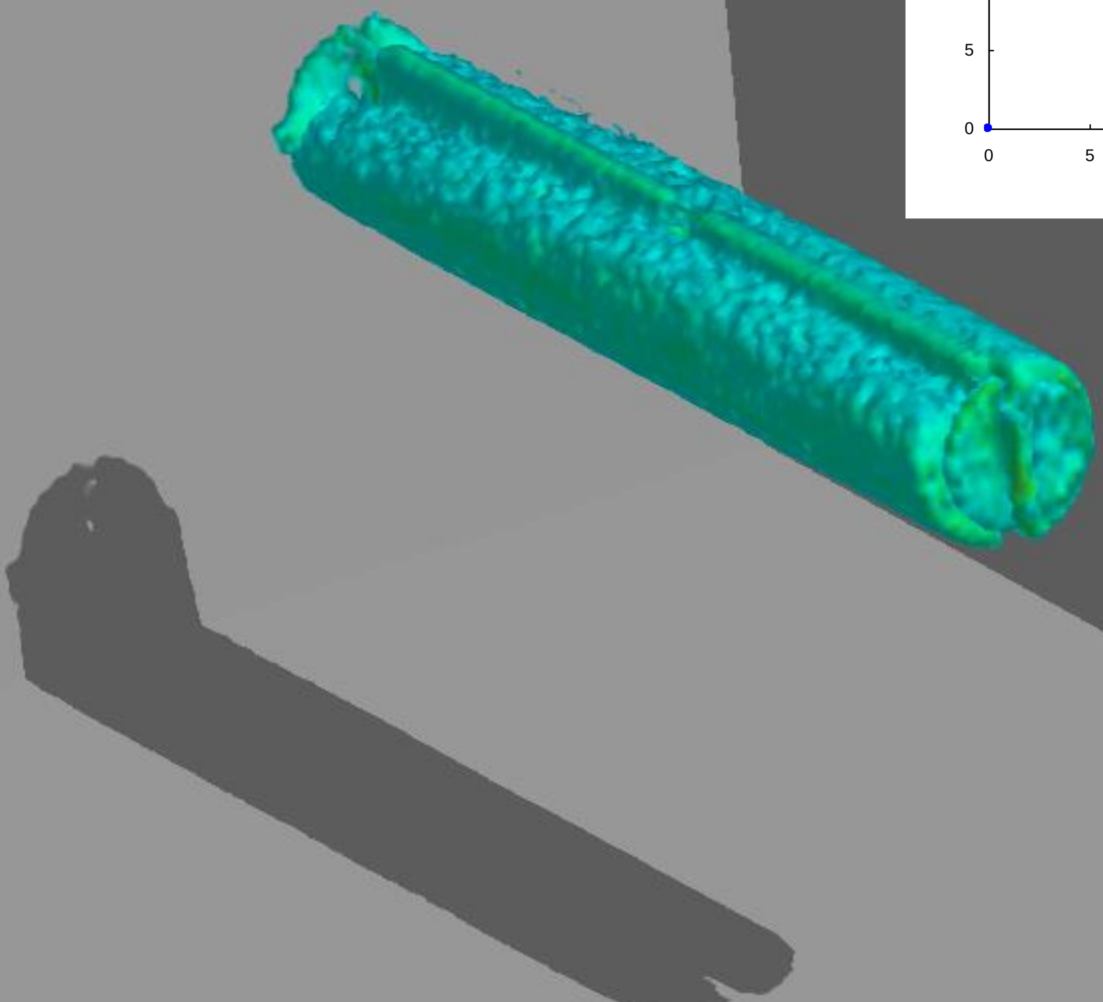
Methane in Spacer

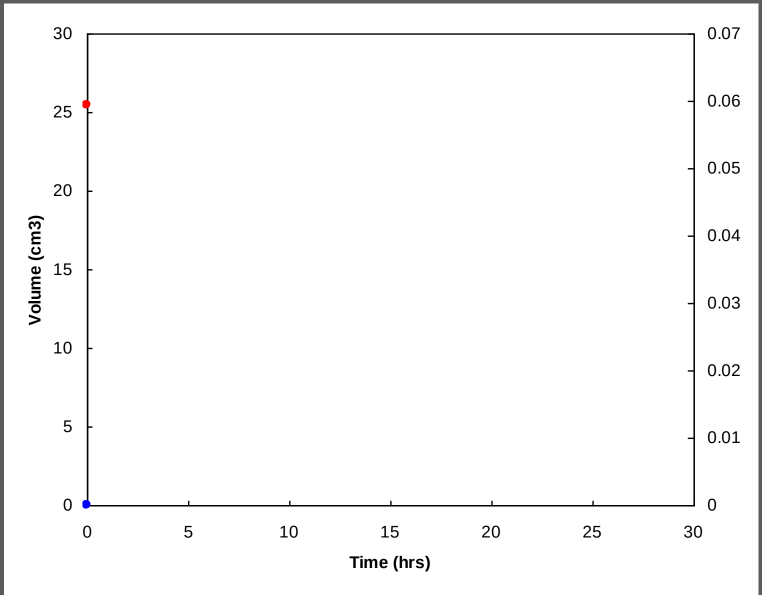


33-07

0.0 hrs

Sw=0.5 + Methane

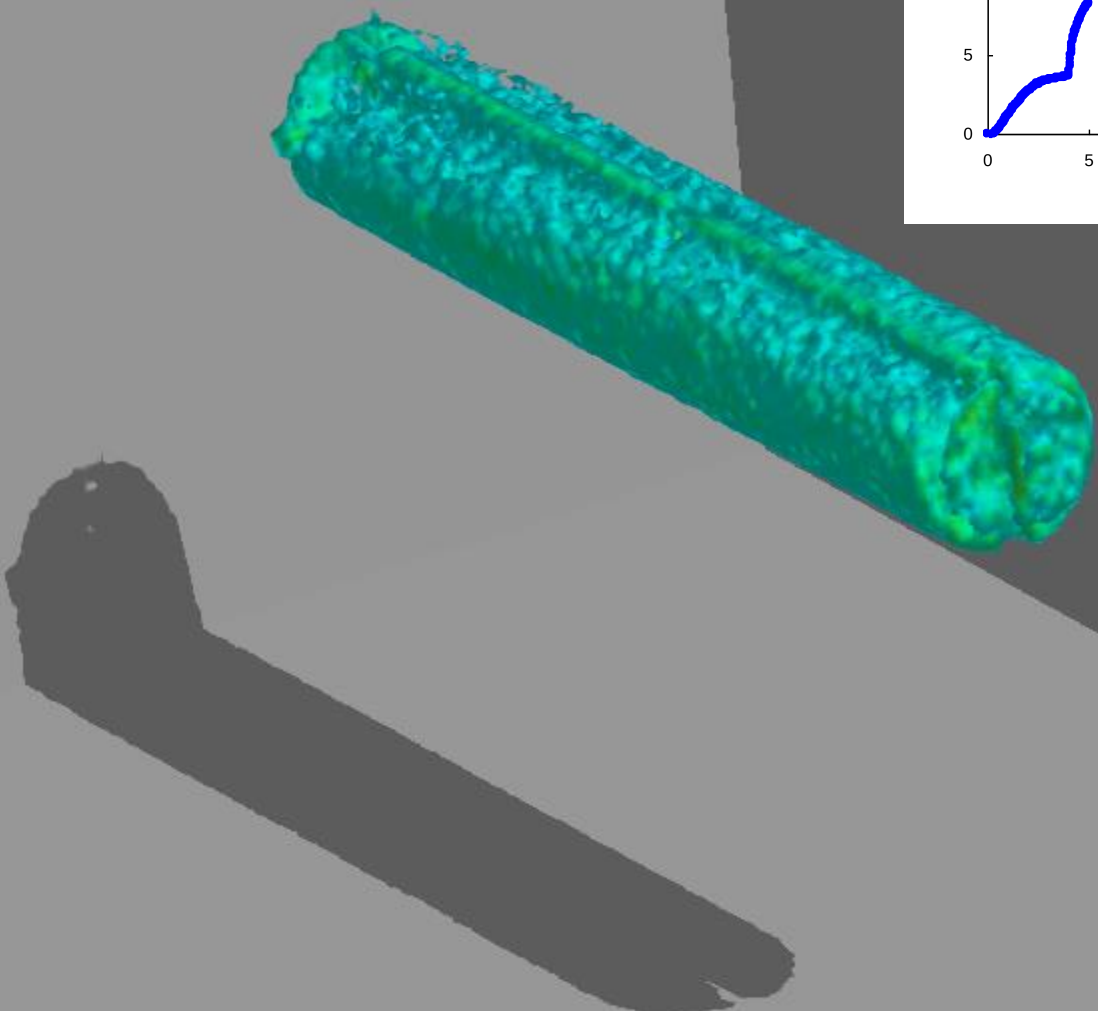


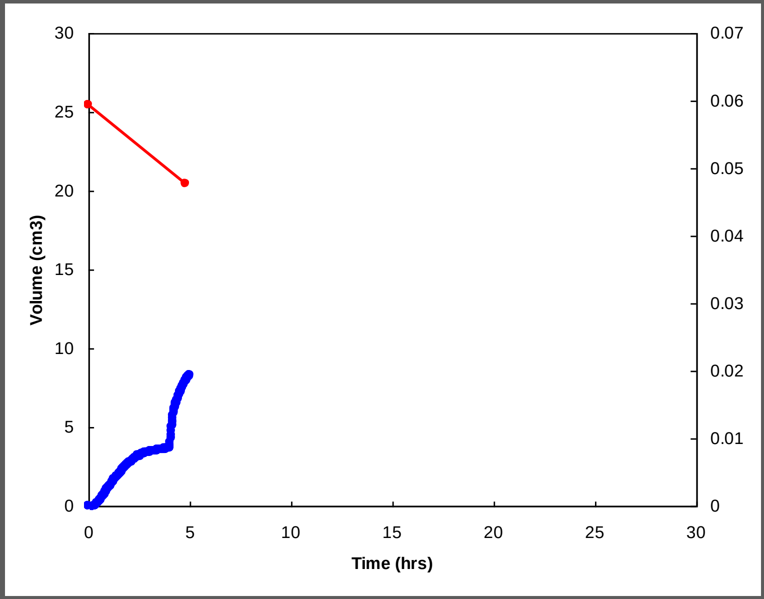


33a-01

5.0 hrs

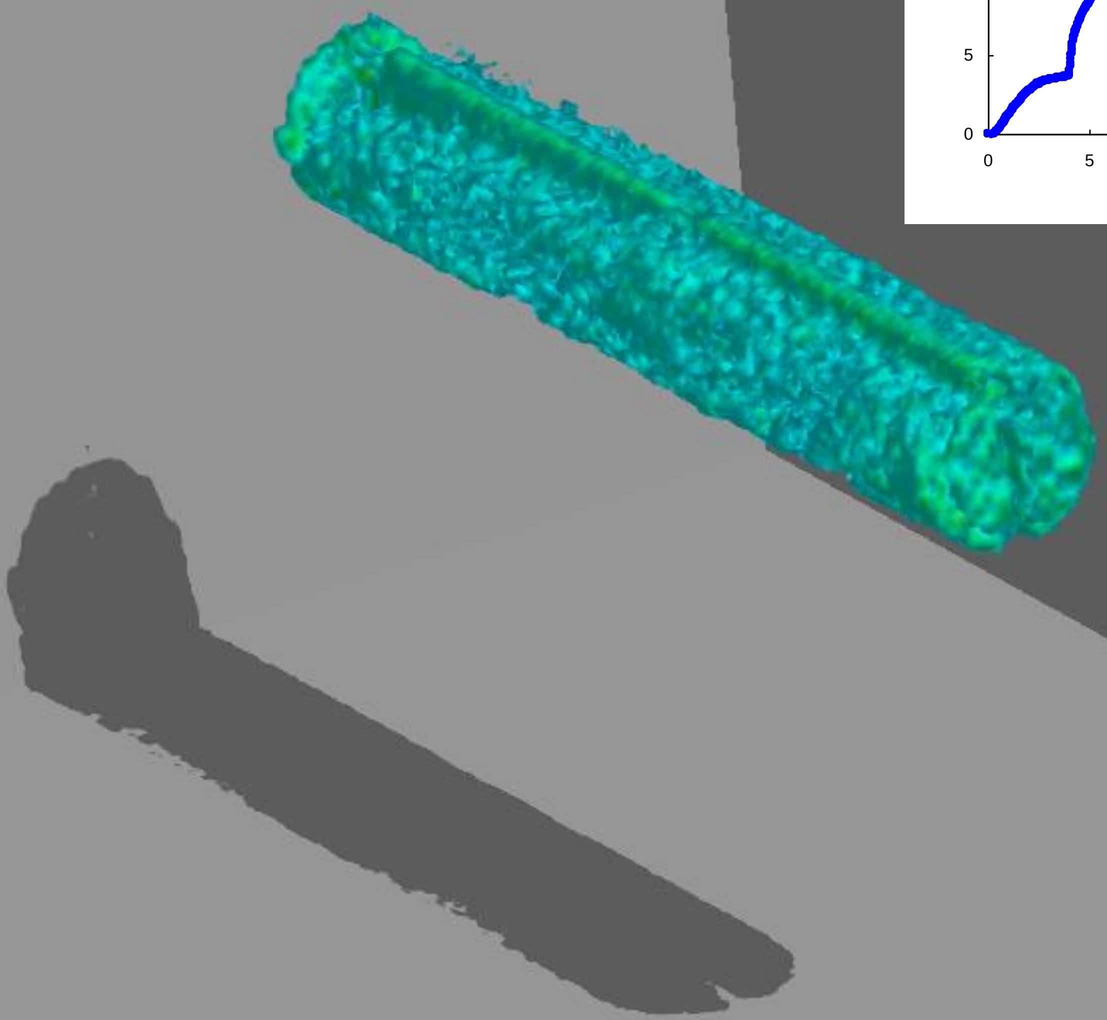
Cooling Starts

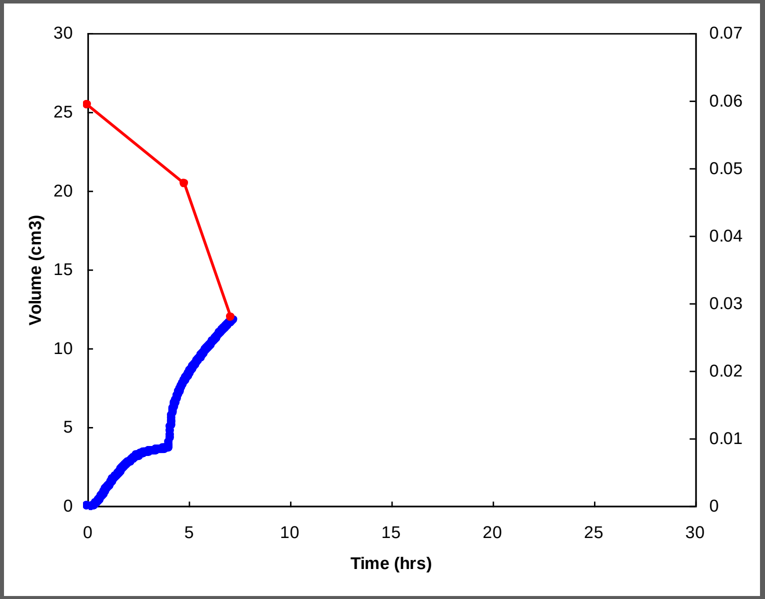




33c-01

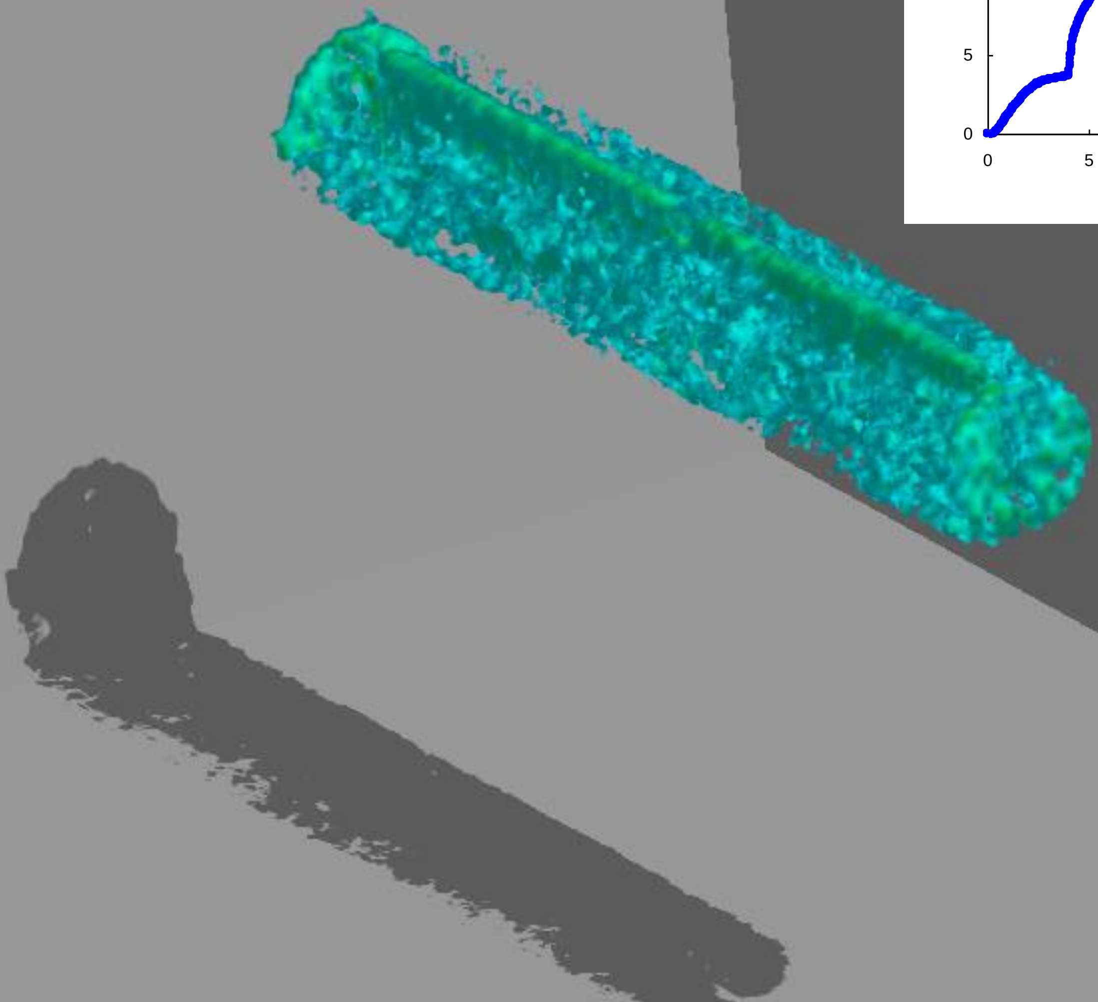
7.2 hrs

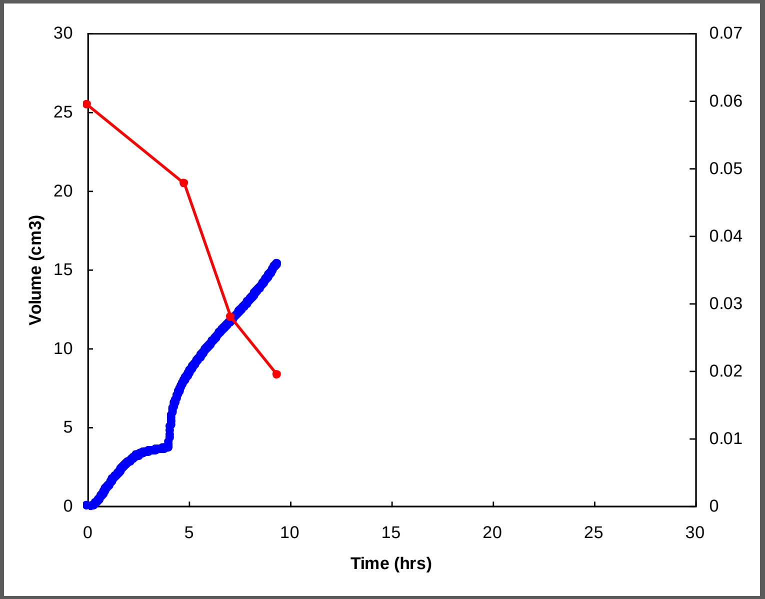


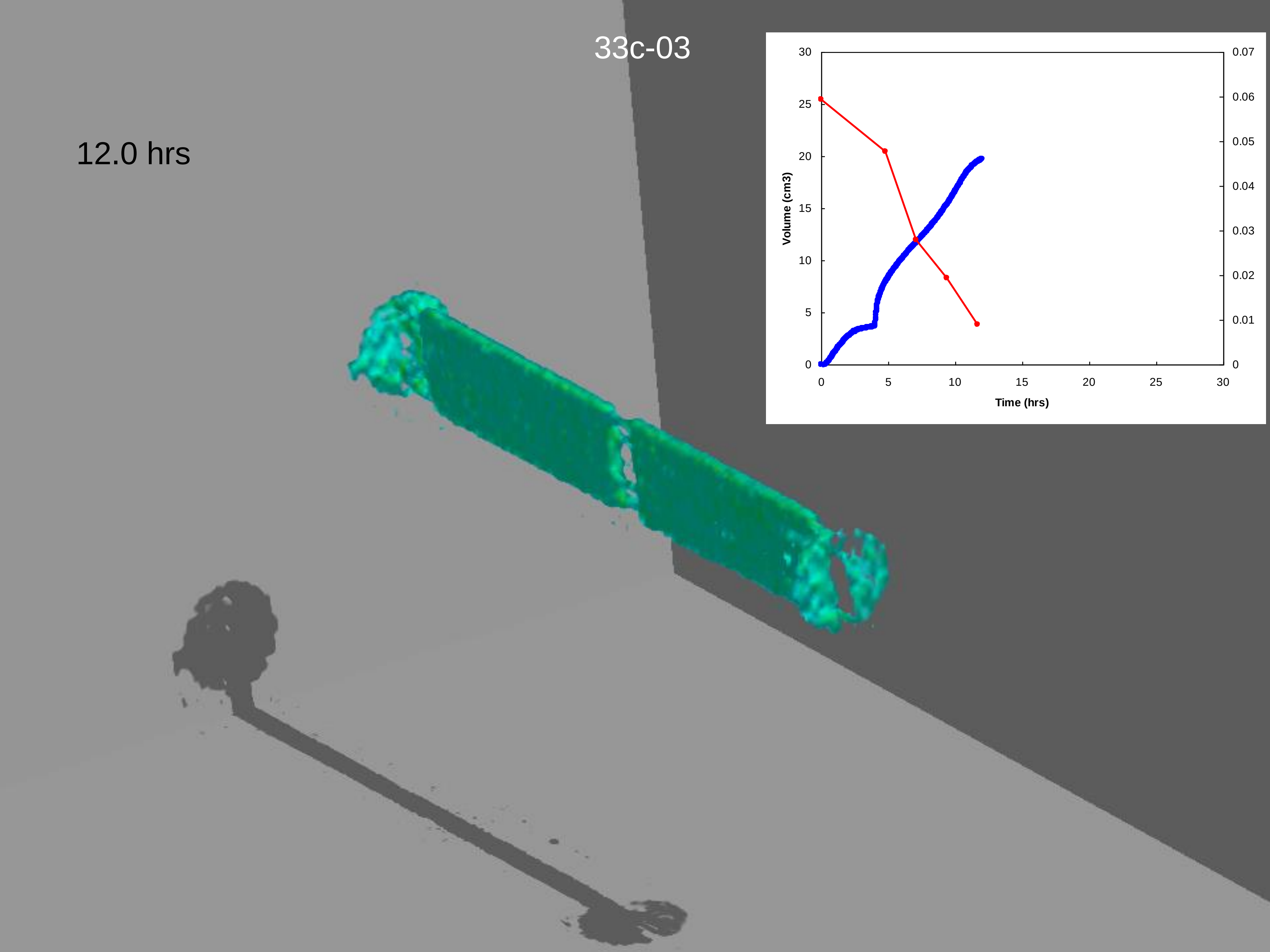


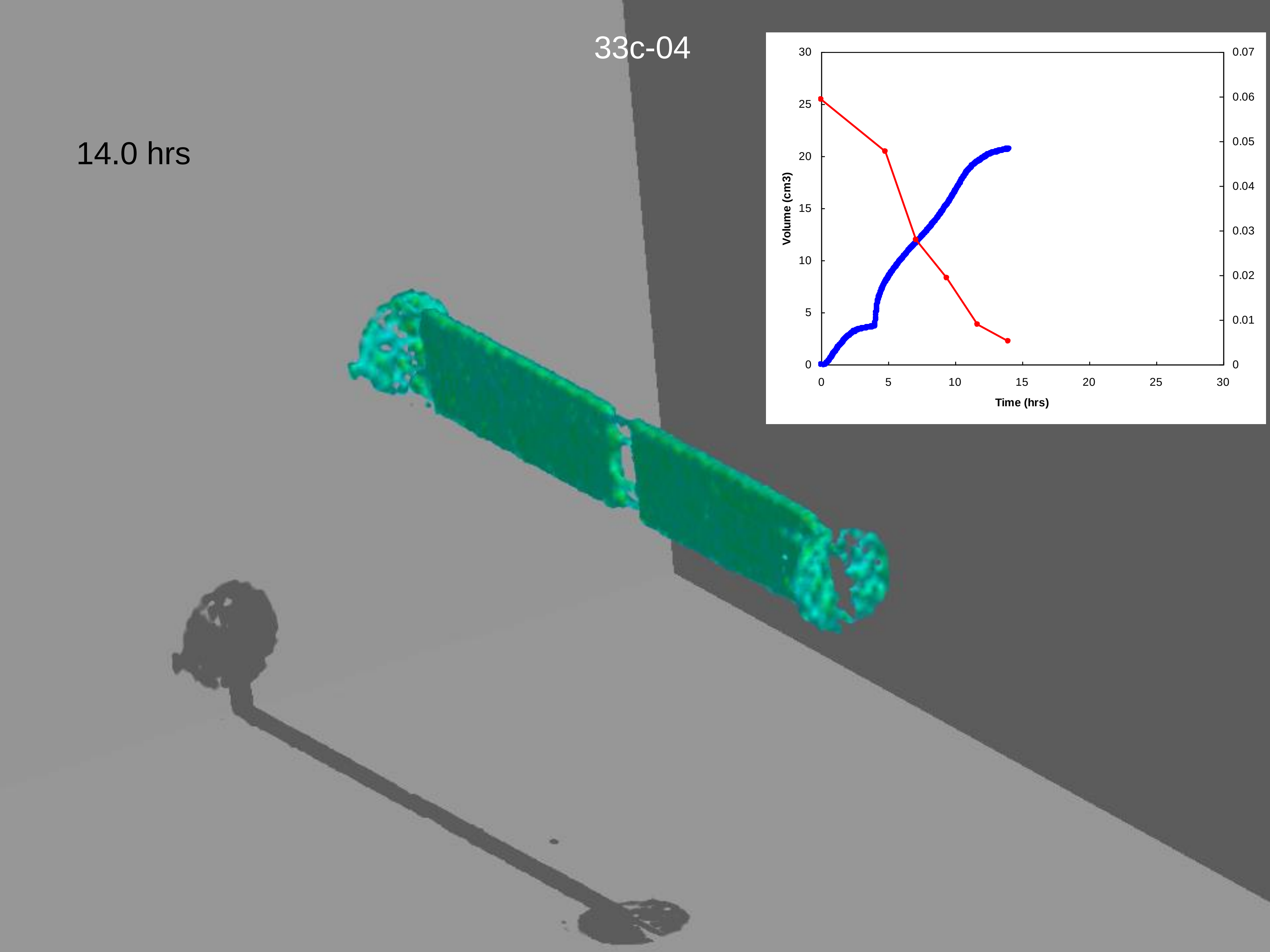
33c-02

9.4 hrs



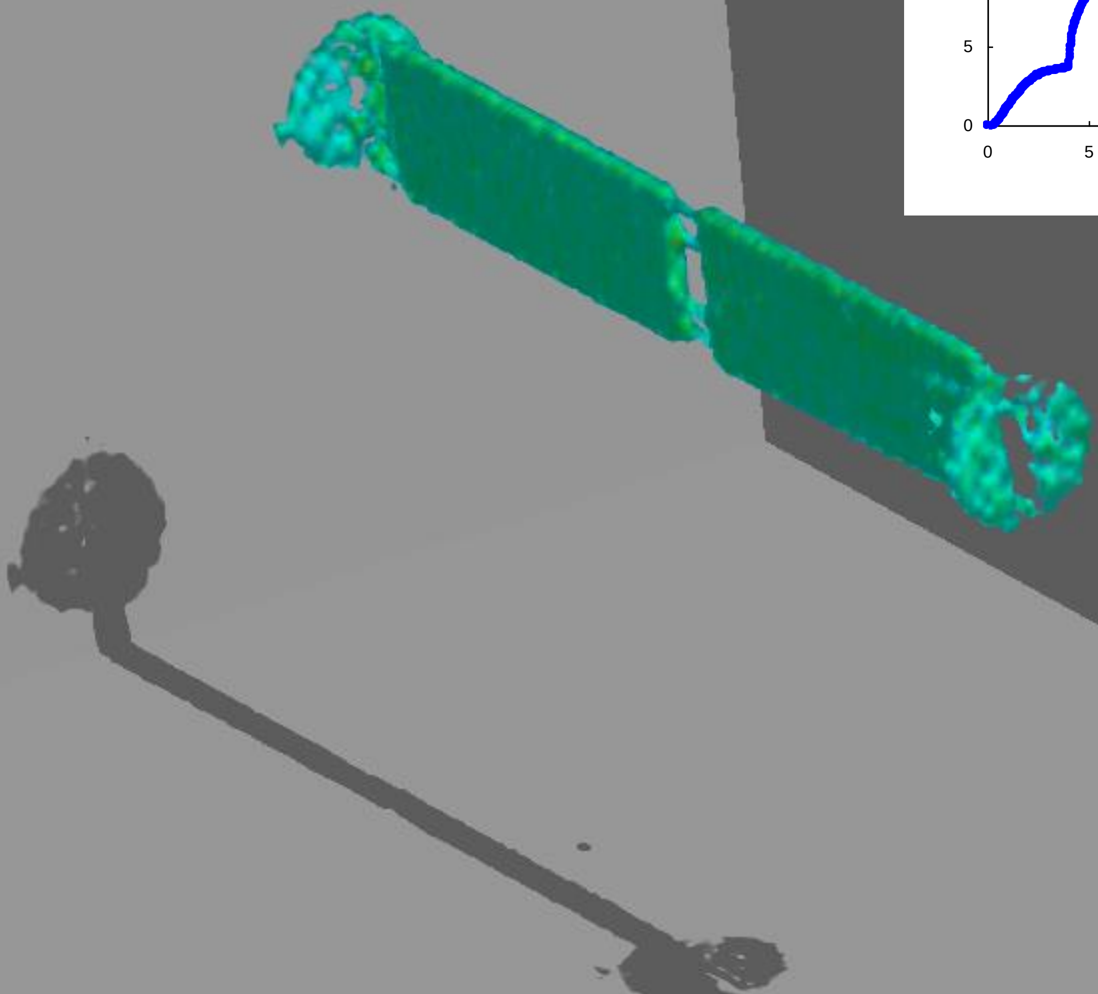


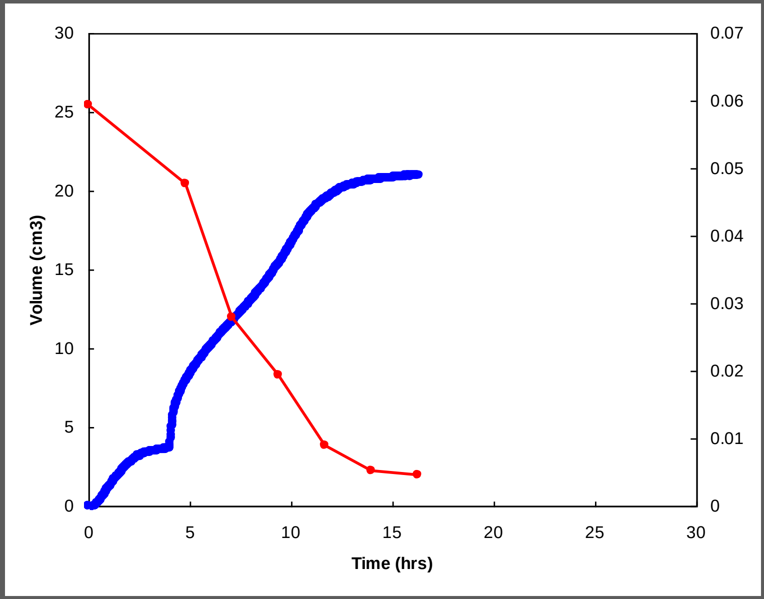

33c-03
12.0 hrs
Volume (cm3)
Time (hrs)
0
5
10
15
20
25
30
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07


33c-04
14.0 hrs
Volume (cm3)
Time (hrs)
0
5
10
15
20
25
30
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07

33c-05

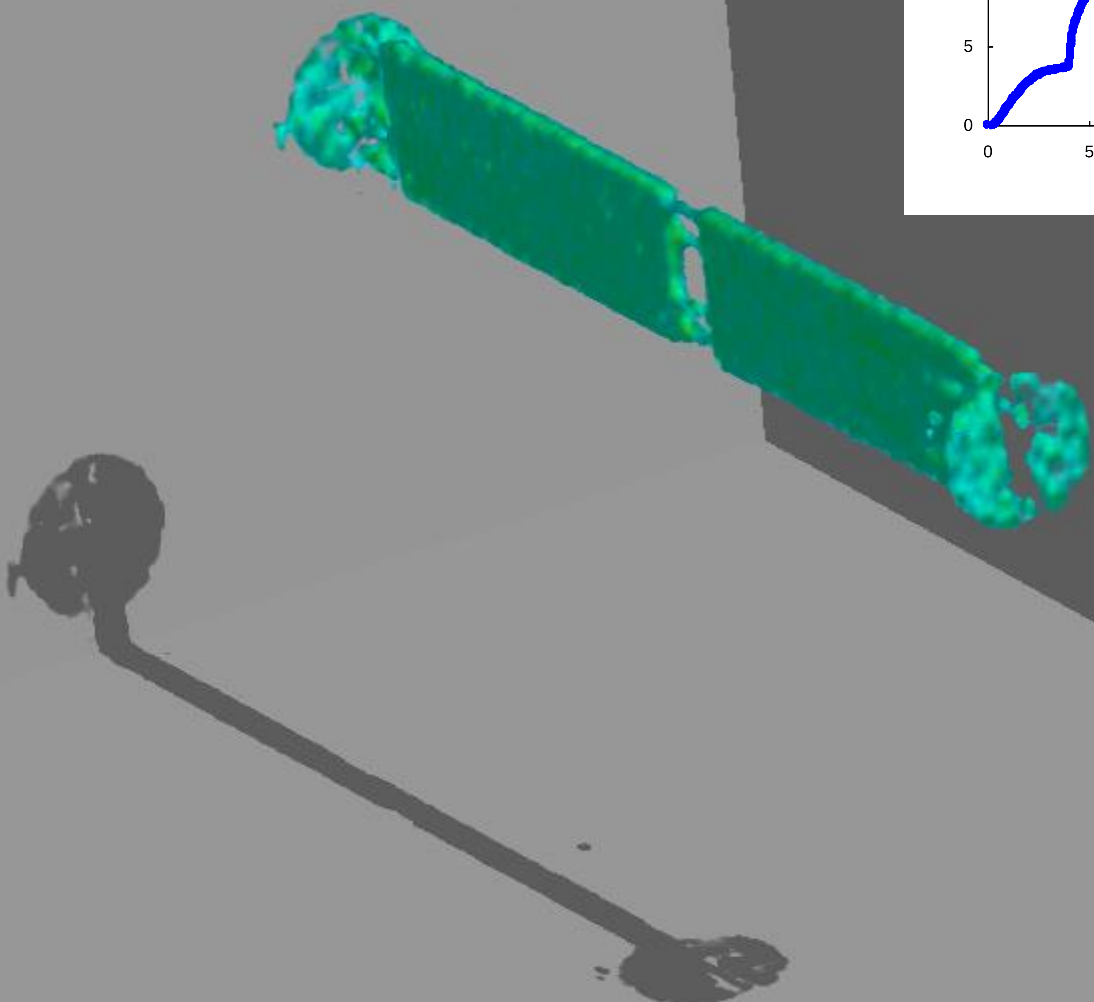
16.3 hrs

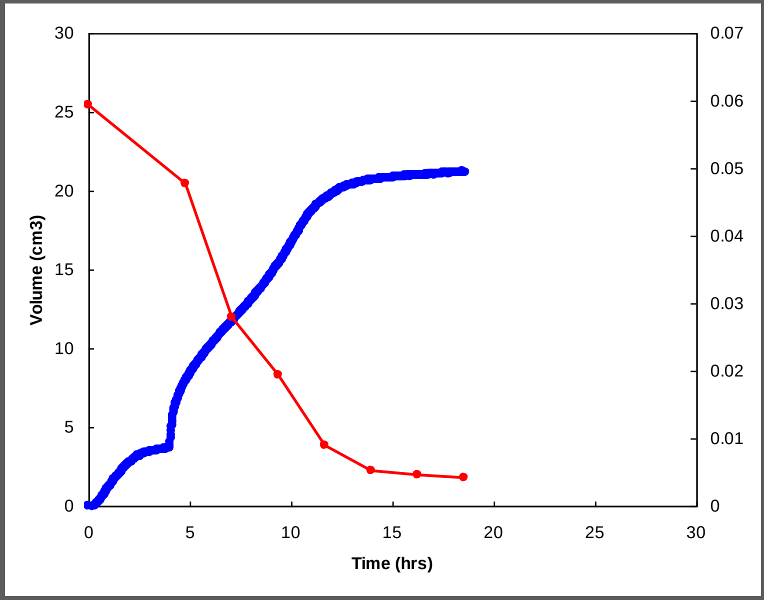




33c-06

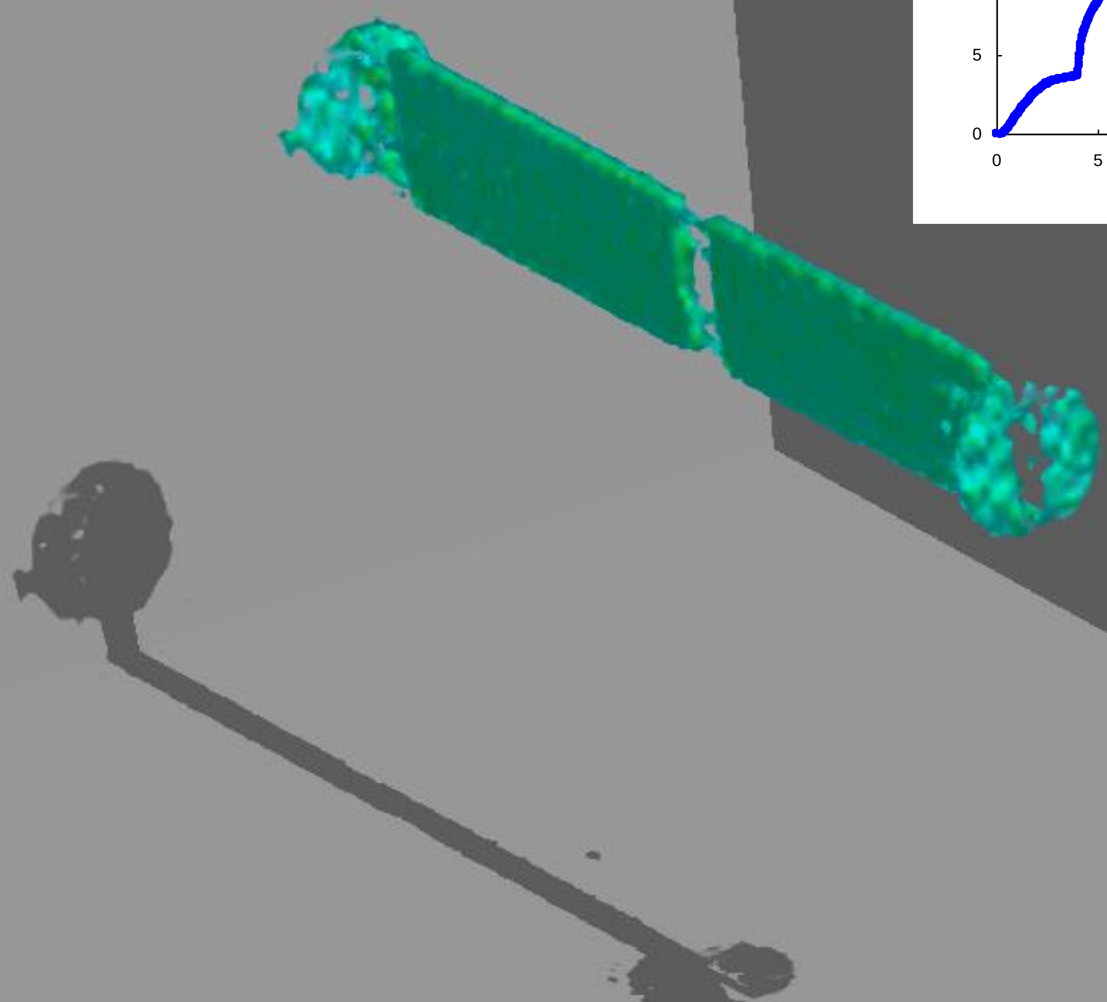
18.6 hrs

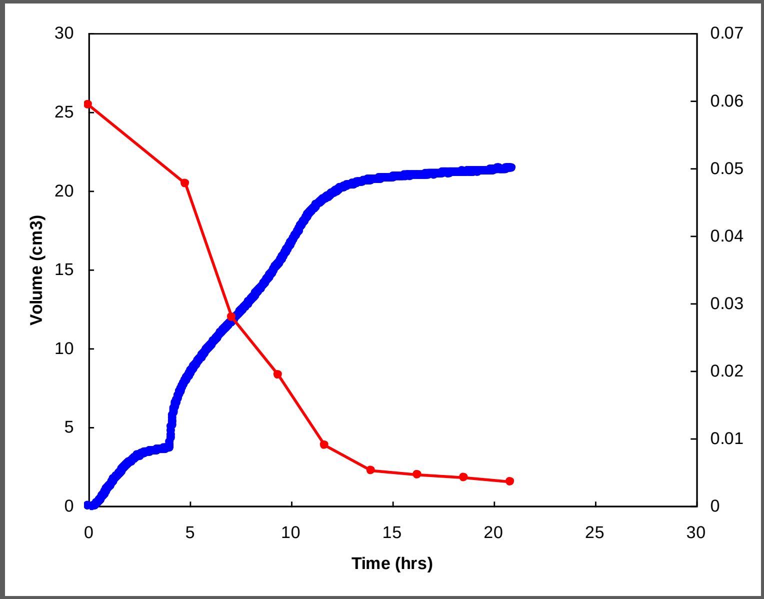




33c-07

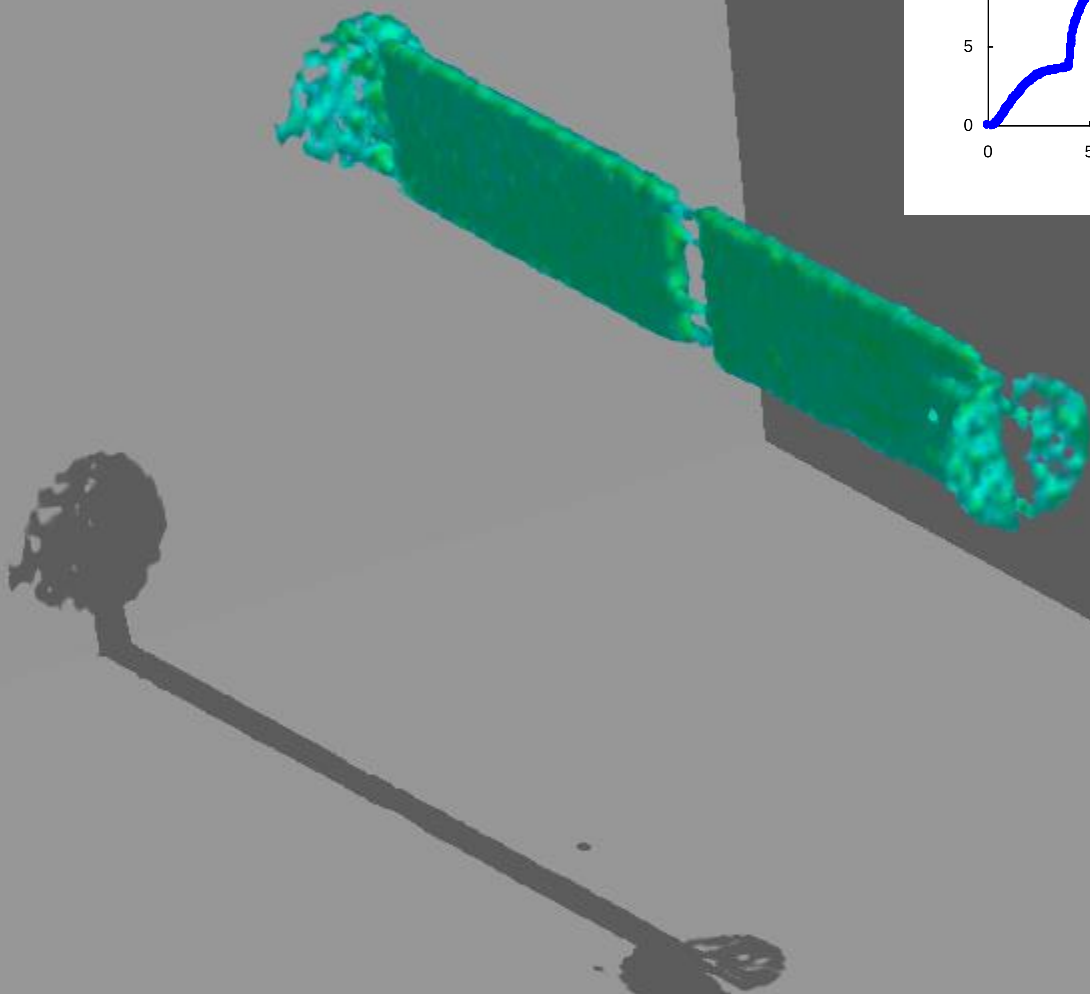
20.9 hrs

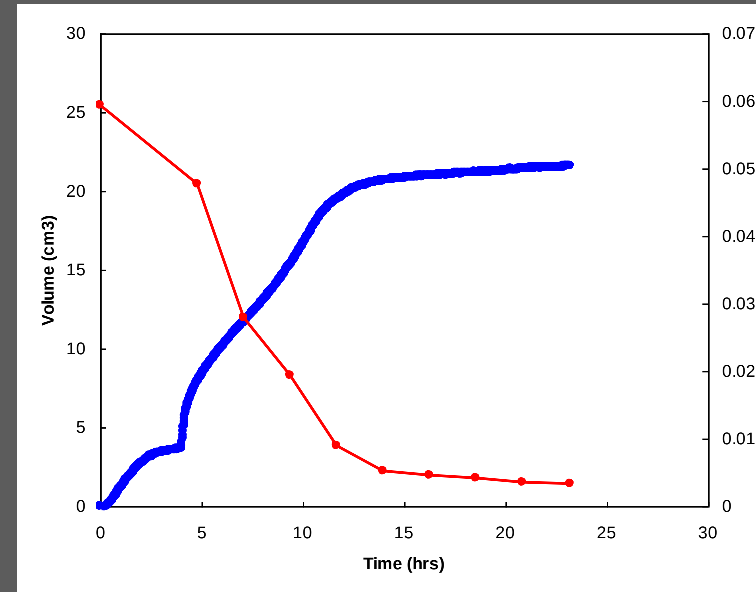




33c-08

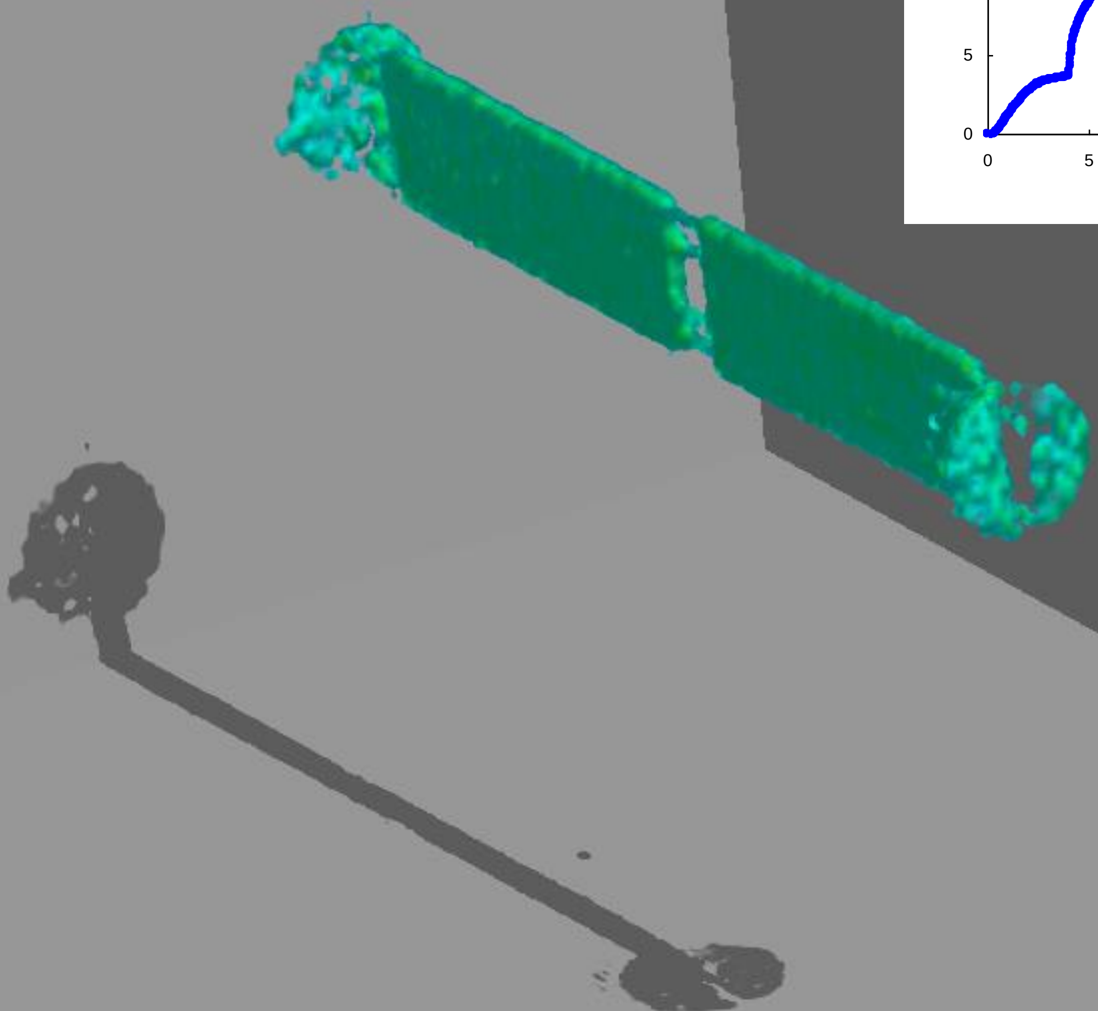
23.2 hrs

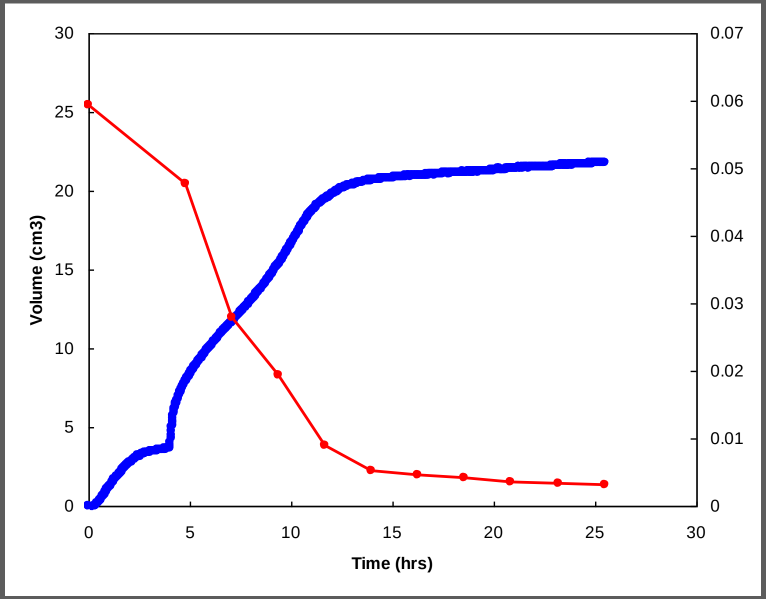


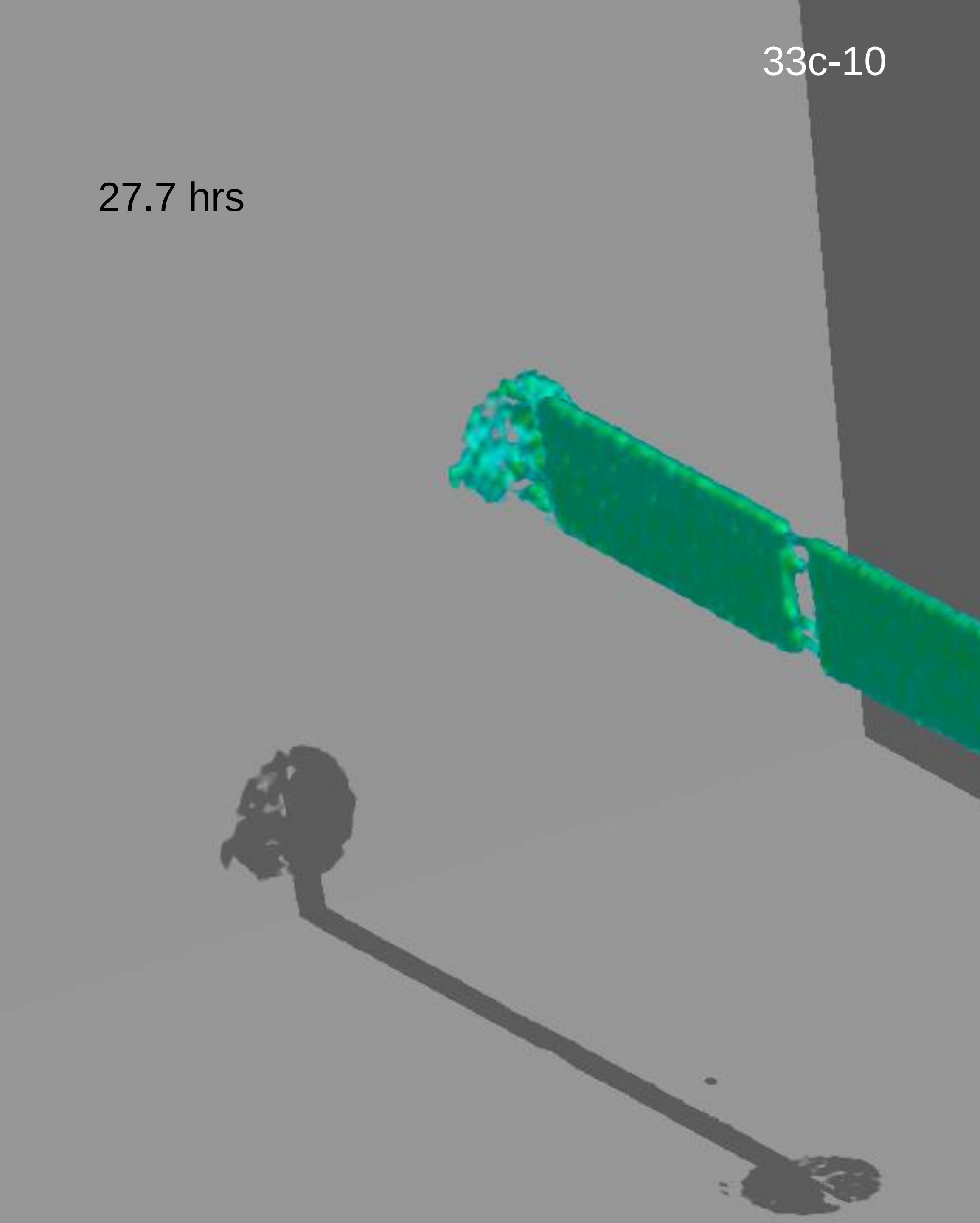
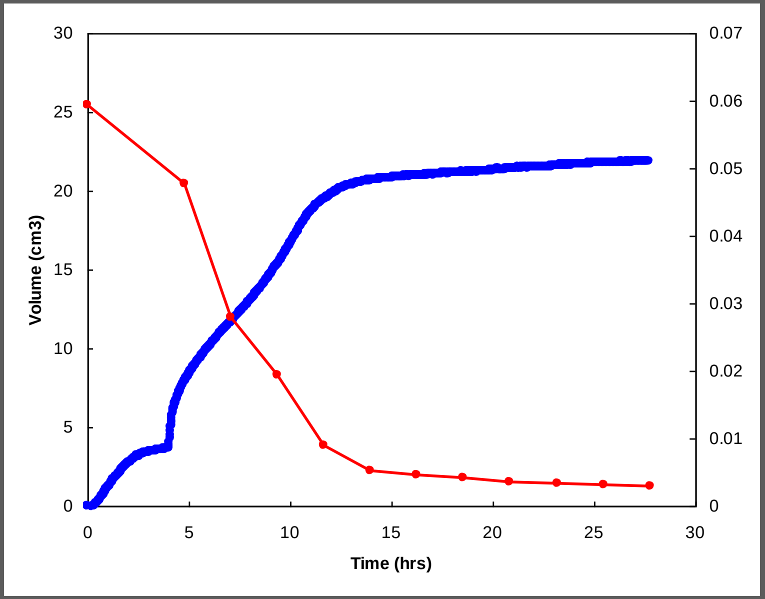


33c-09

25.5 hrs

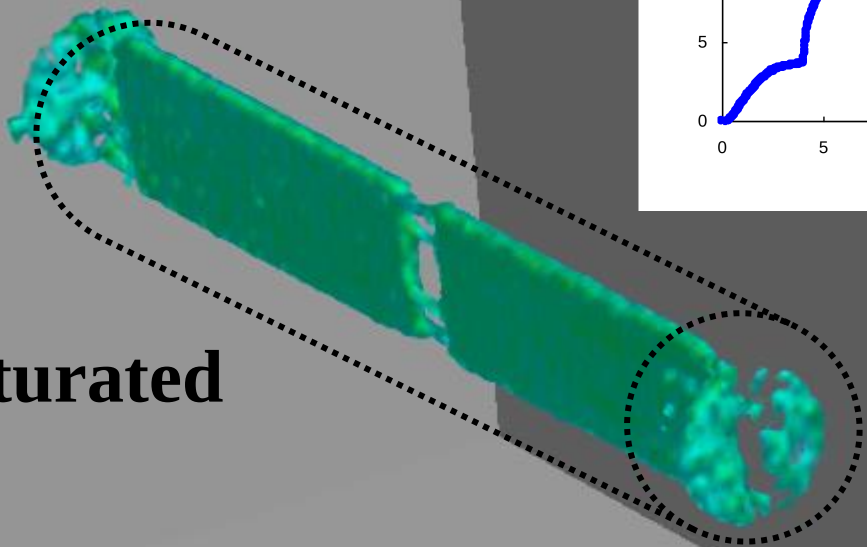


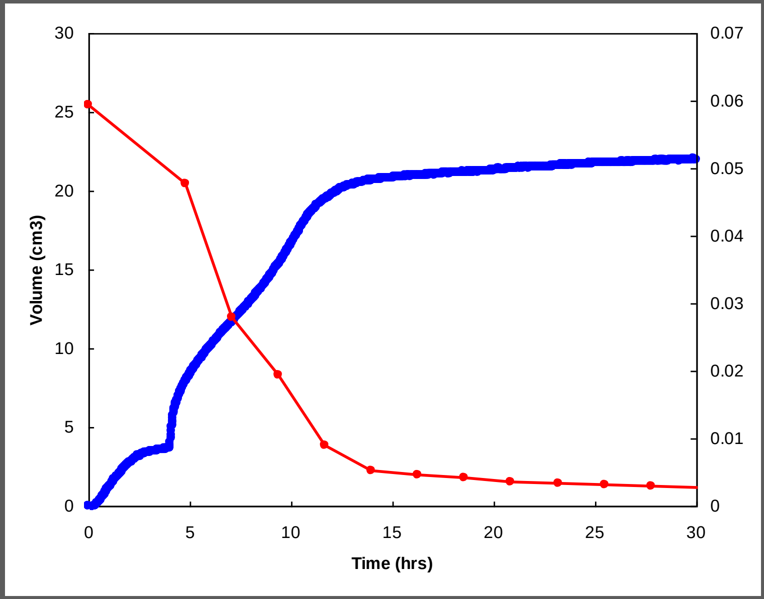



33c-10
27.7 hrs

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

33c-11

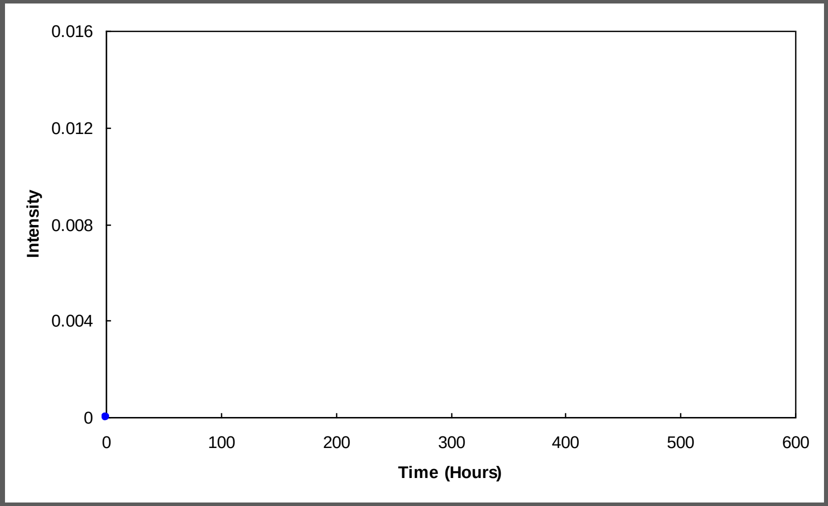
30.0 hrs





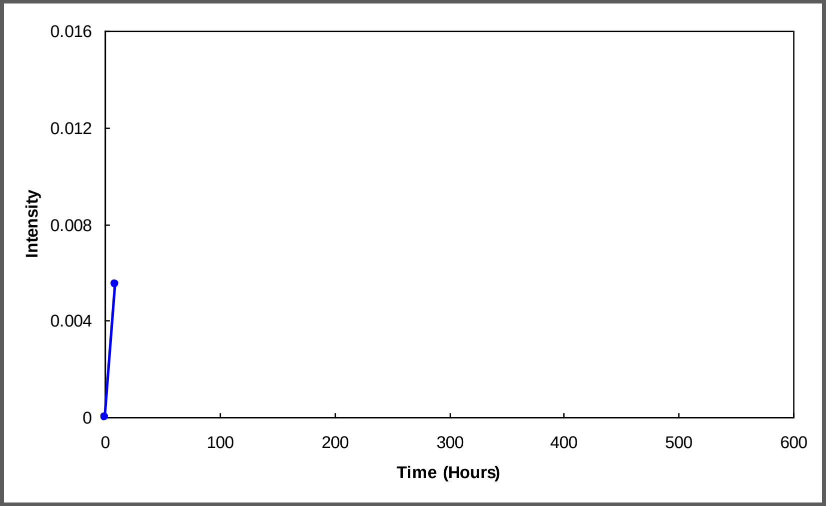
Core Halves Saturated with hydrate

0.0 hrs


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

34a-01

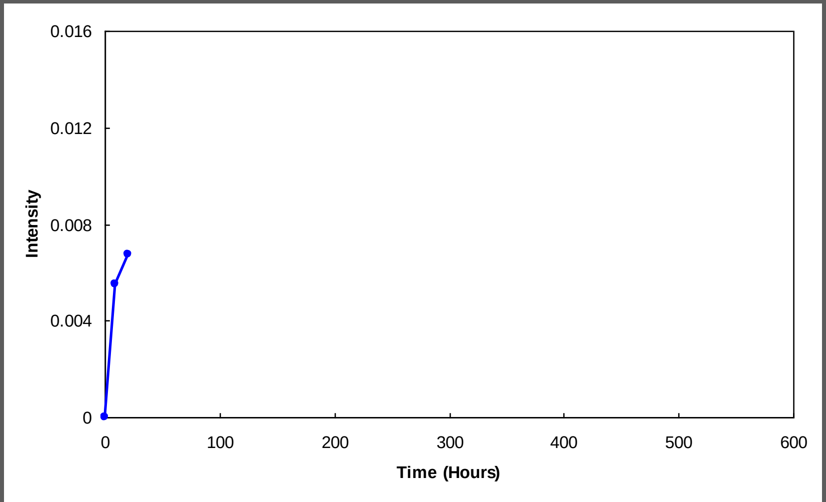
9.1 hrs



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

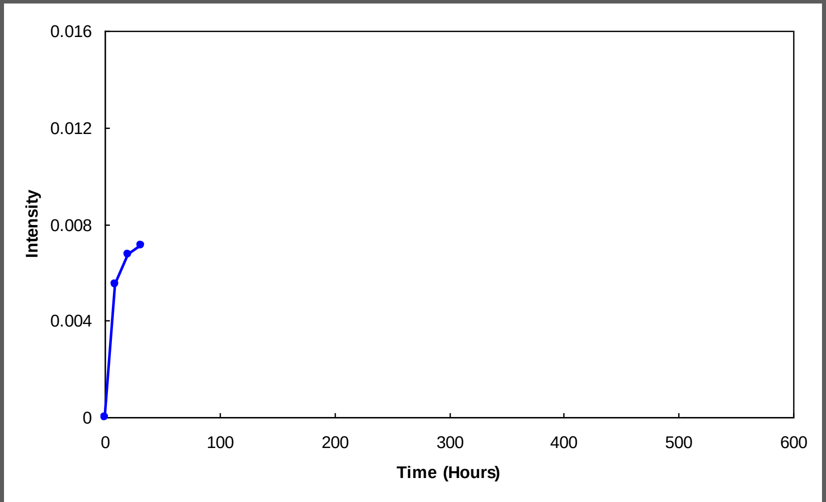
34b-01

20.6 hrs



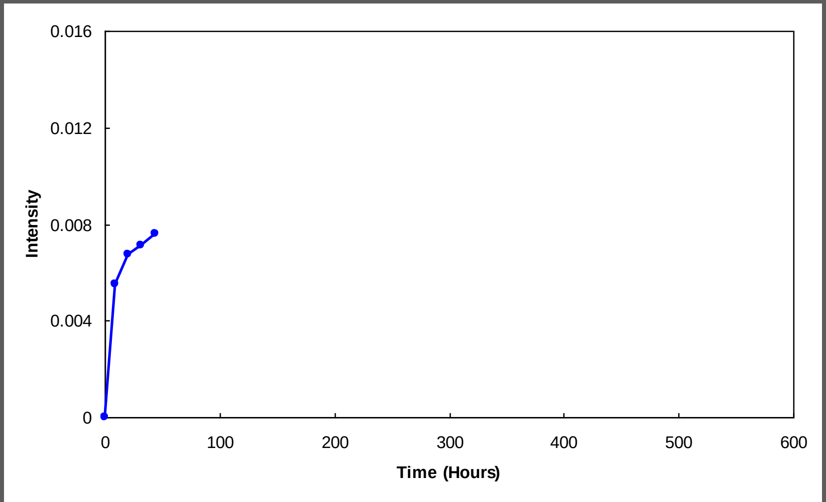
34b-02

32.0 hrs



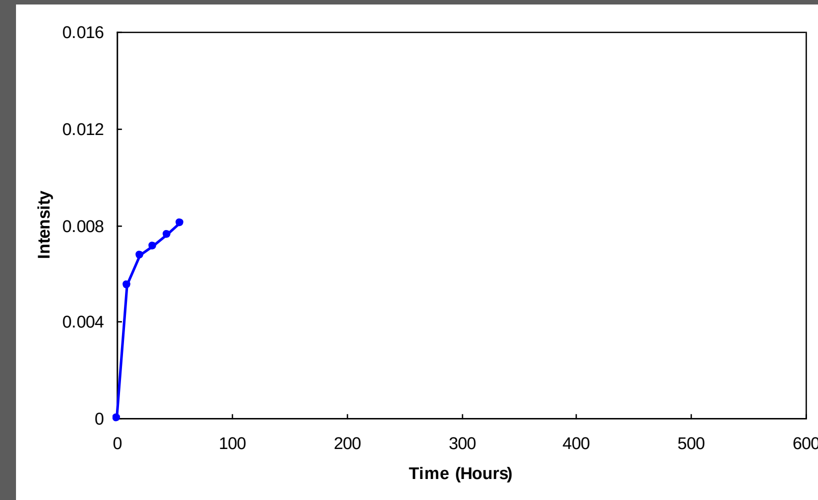
34b-03

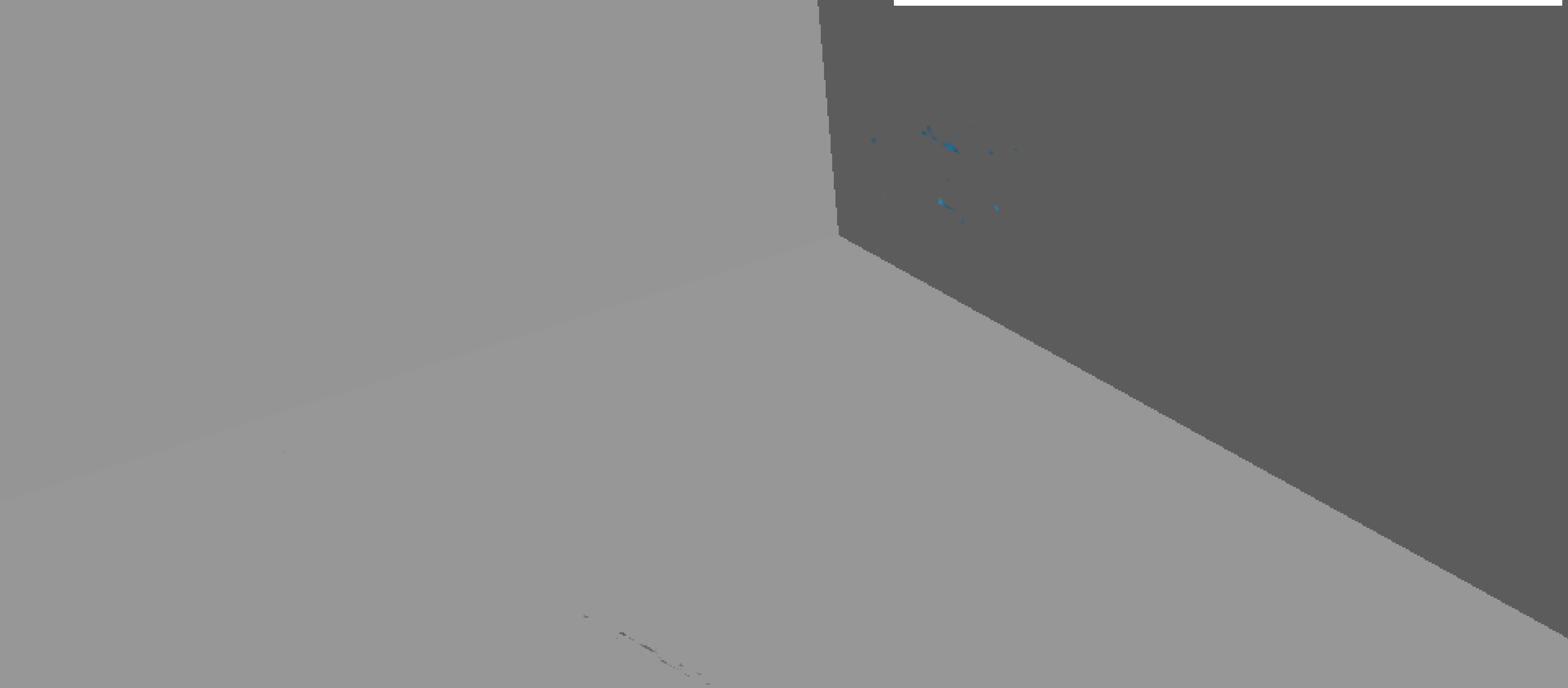
43.4 hrs

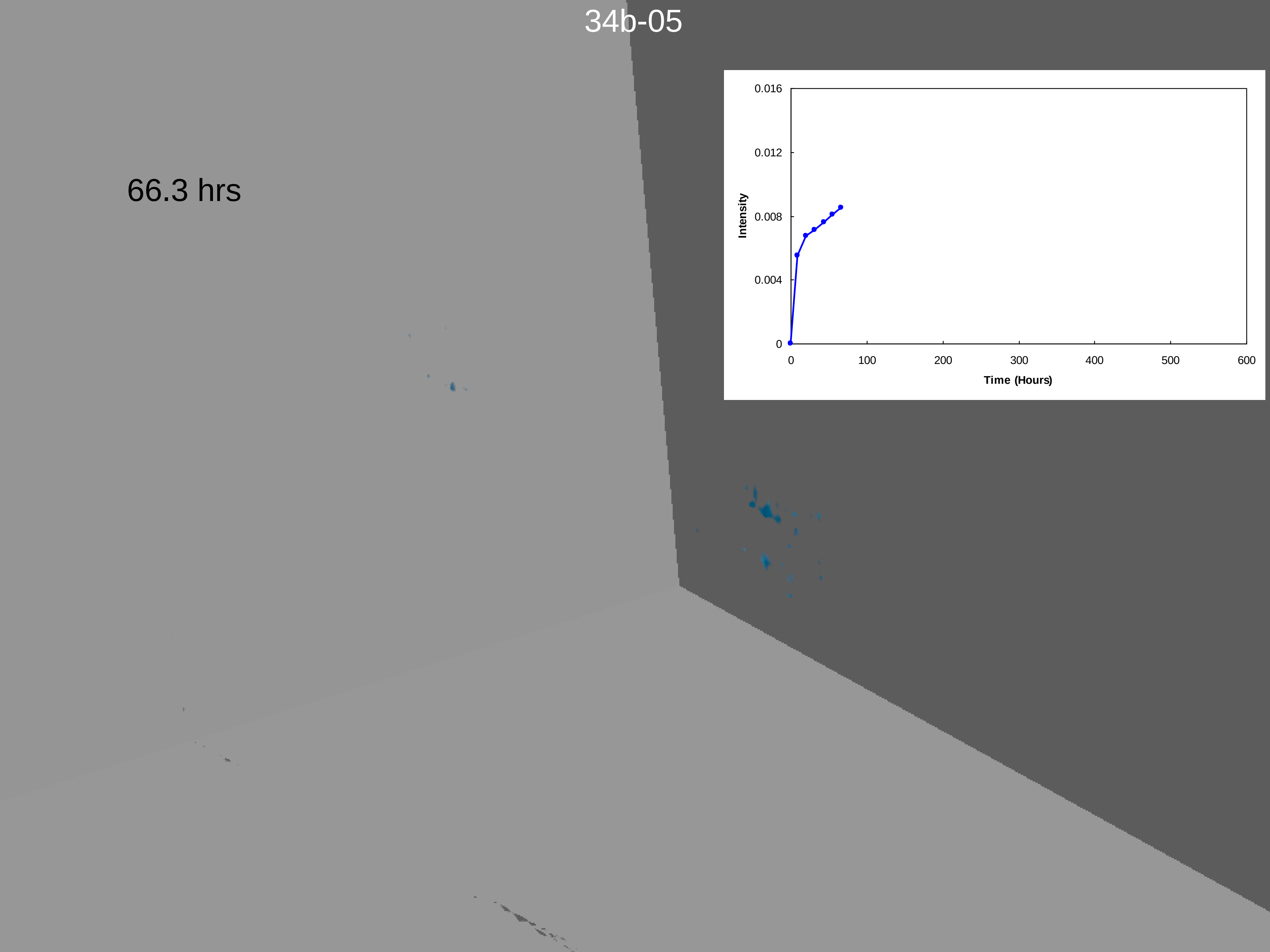


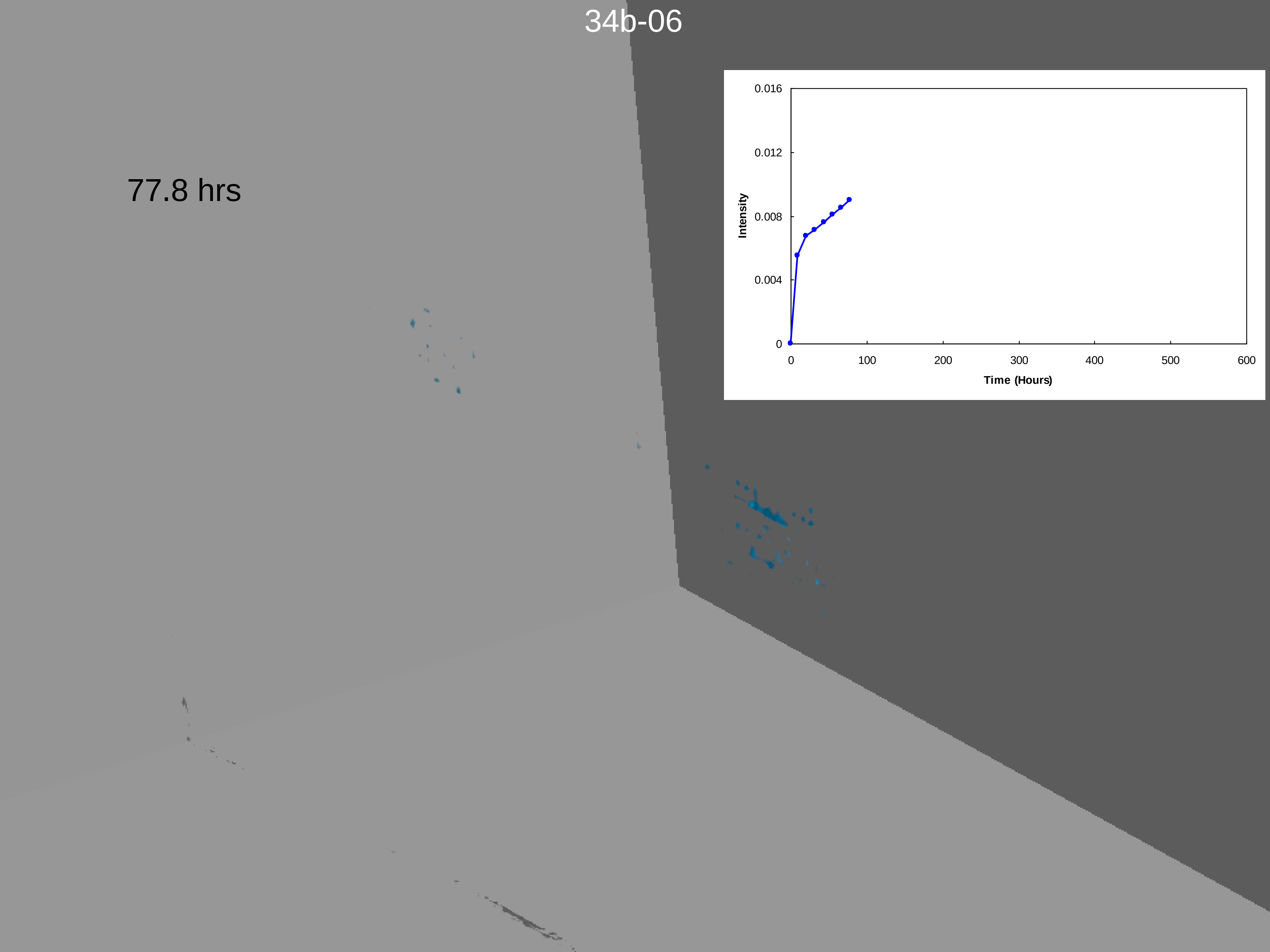
34b-04

54.9 hrs

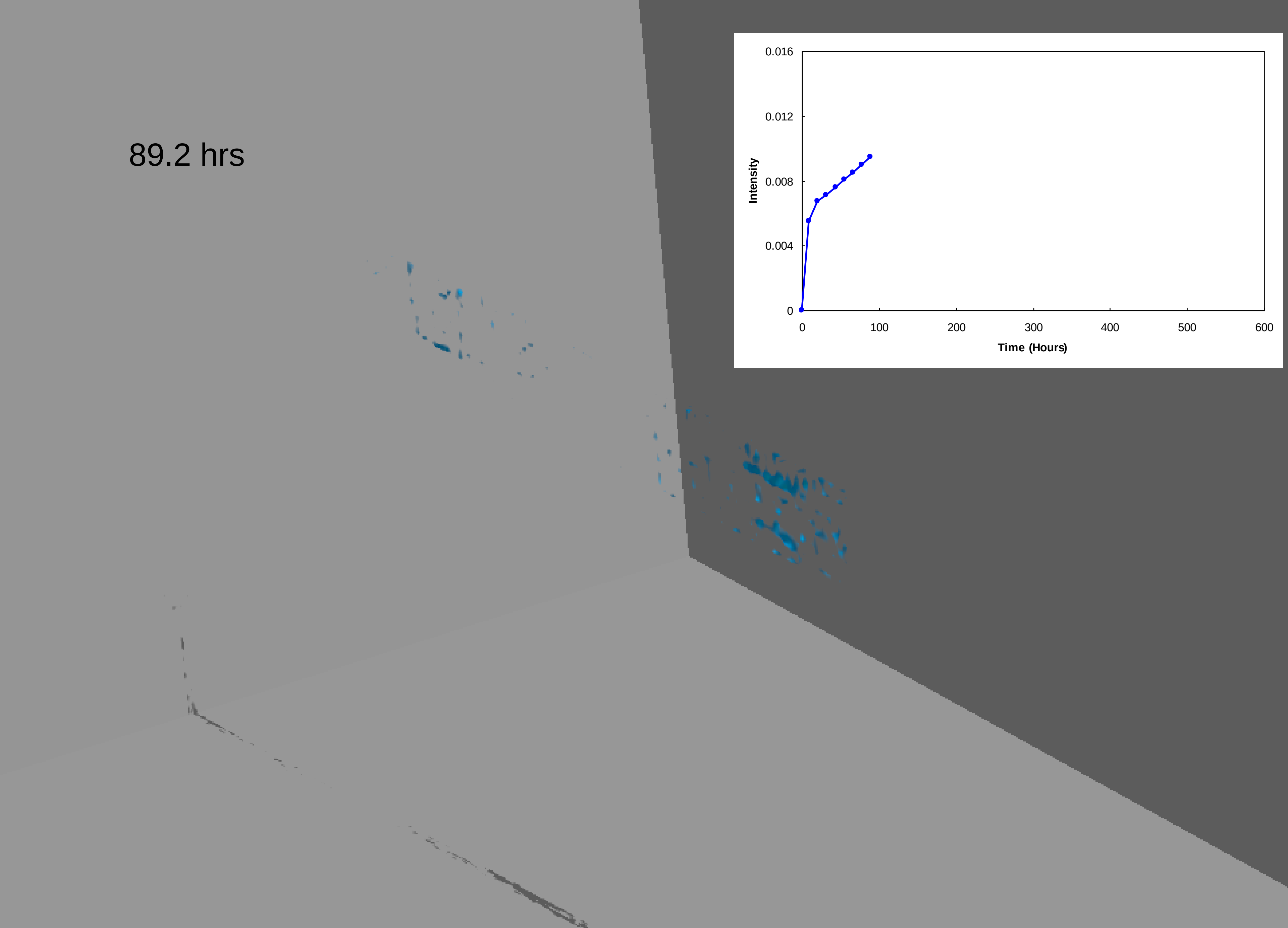





34b-05
66.3 hrs
0.016
0.012
0.008
0.004
0
Intensity
0
100
200
300
400
500
600
Time (Hours)

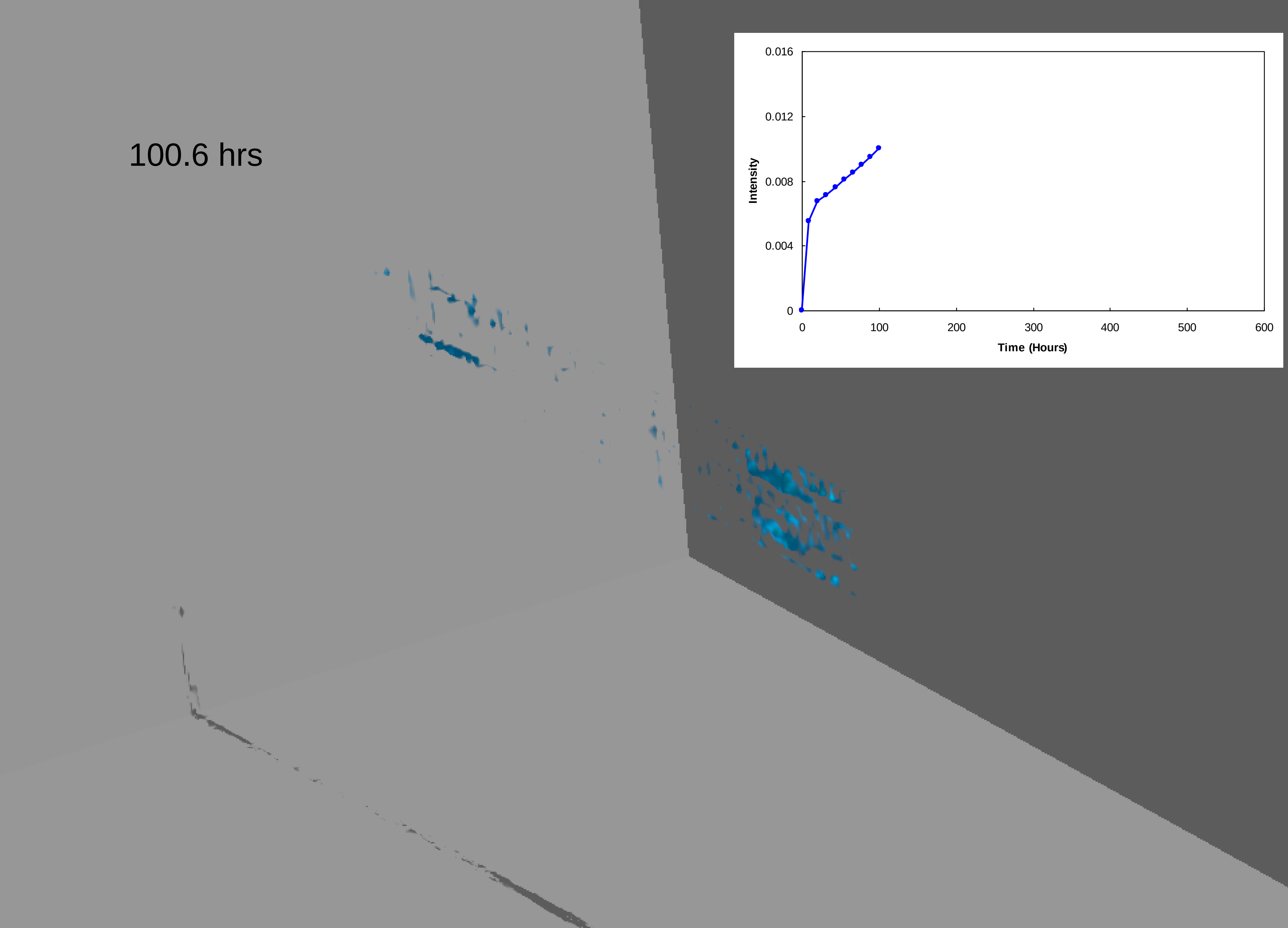

34b-06
77.8 hrs
0.016
0.012
0.008
0.004
0
Intensity
0
100
200
300
400
500
600
Time (Hours)

34b-07


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

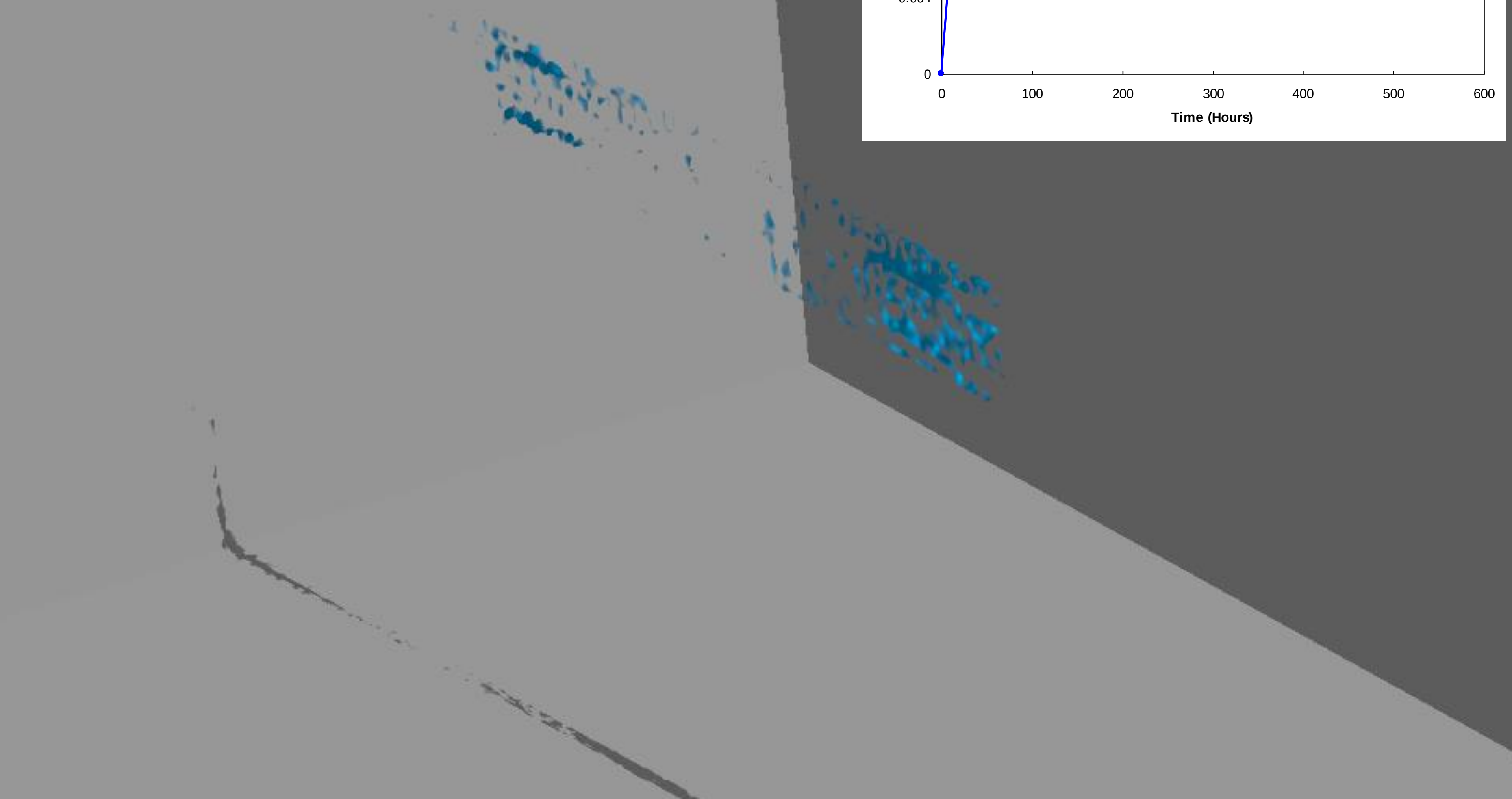
34b-08

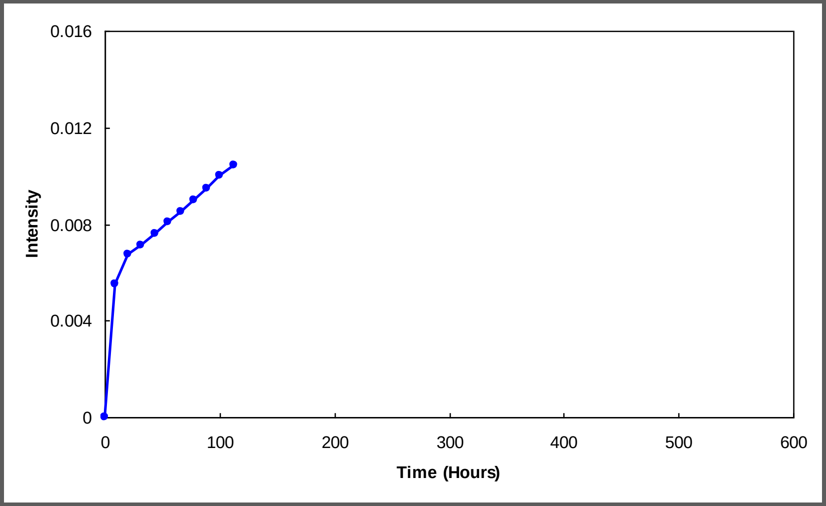
100.6 hrs



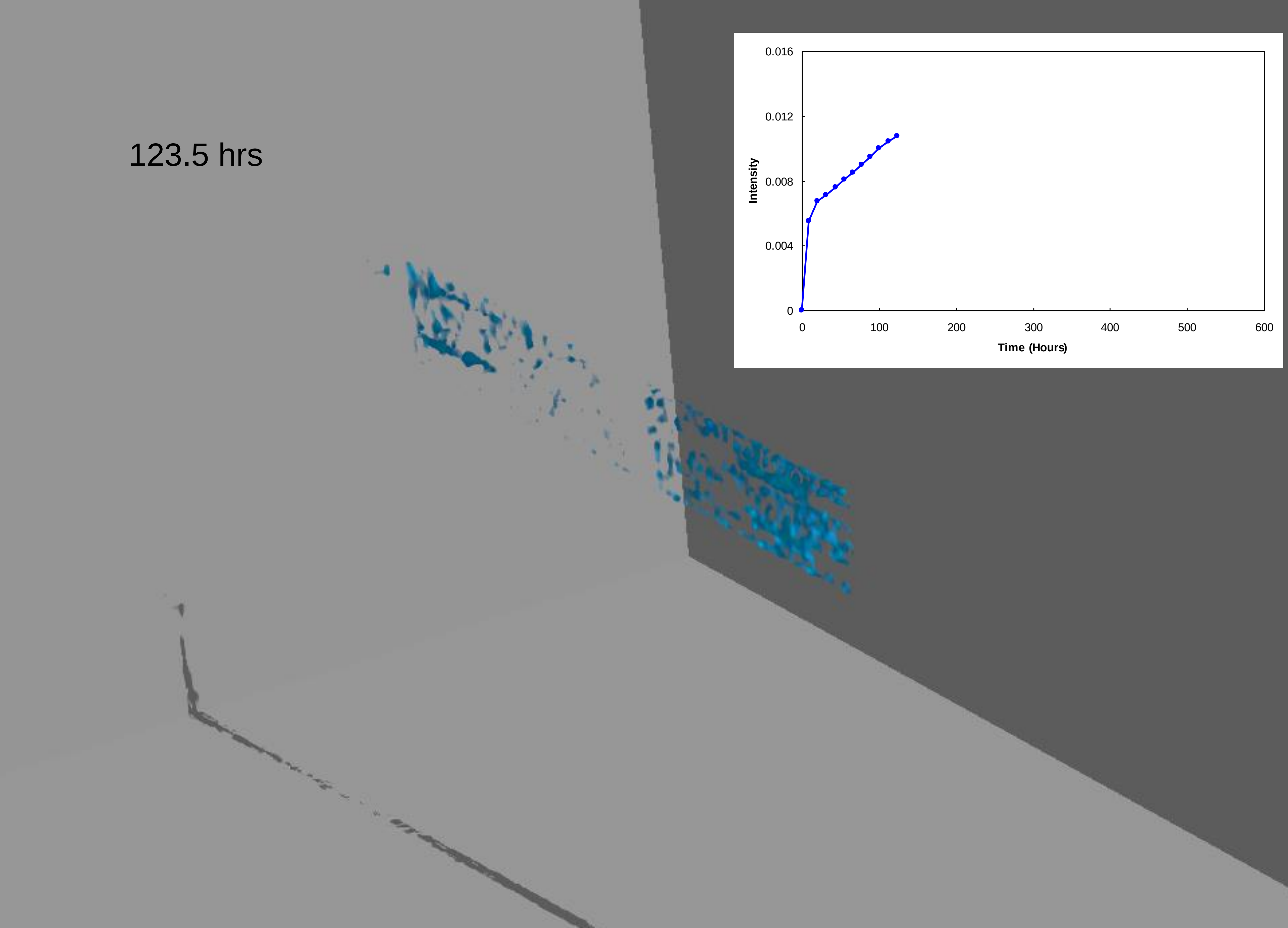
34b-09

112.1 hrs

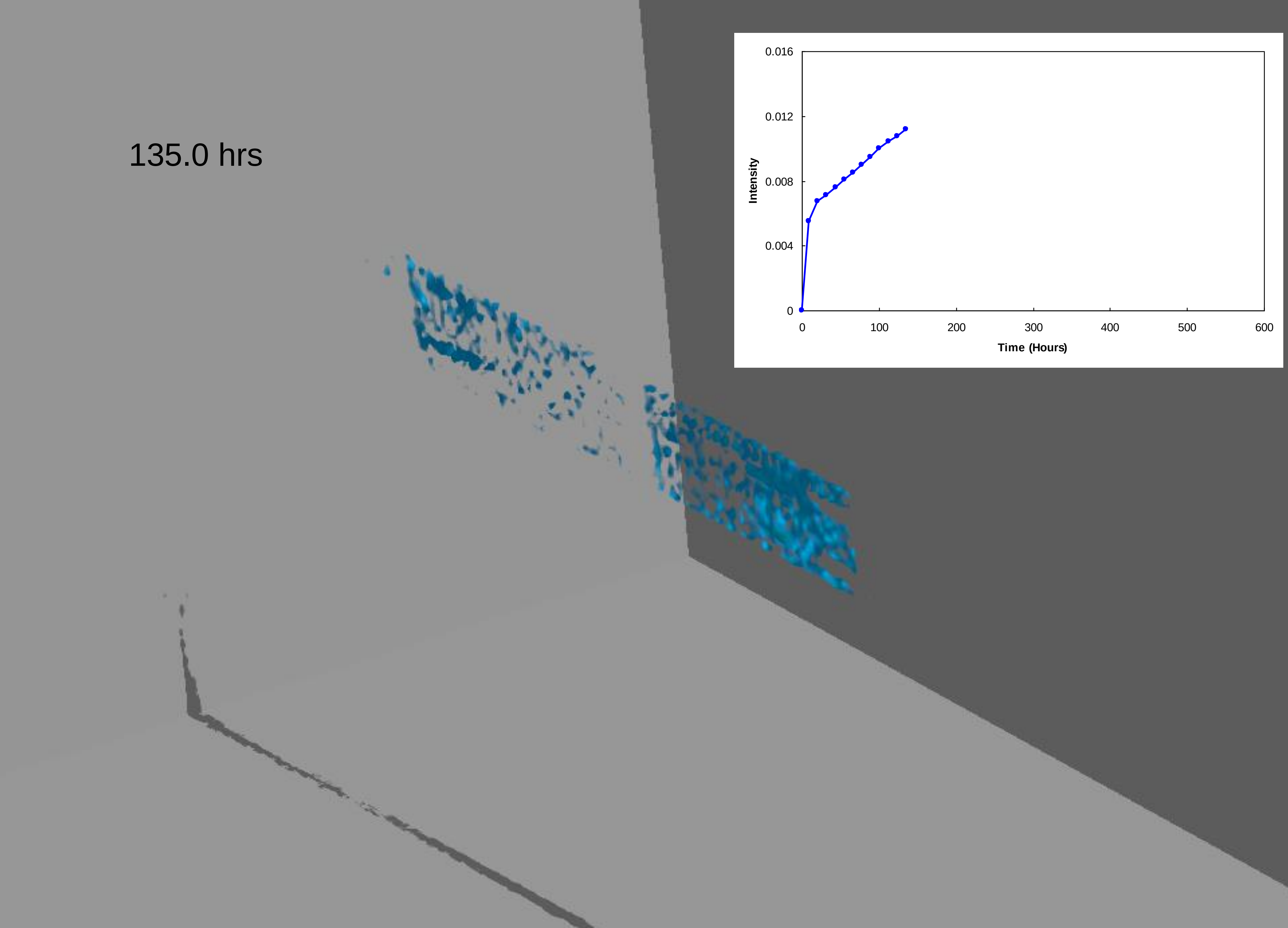




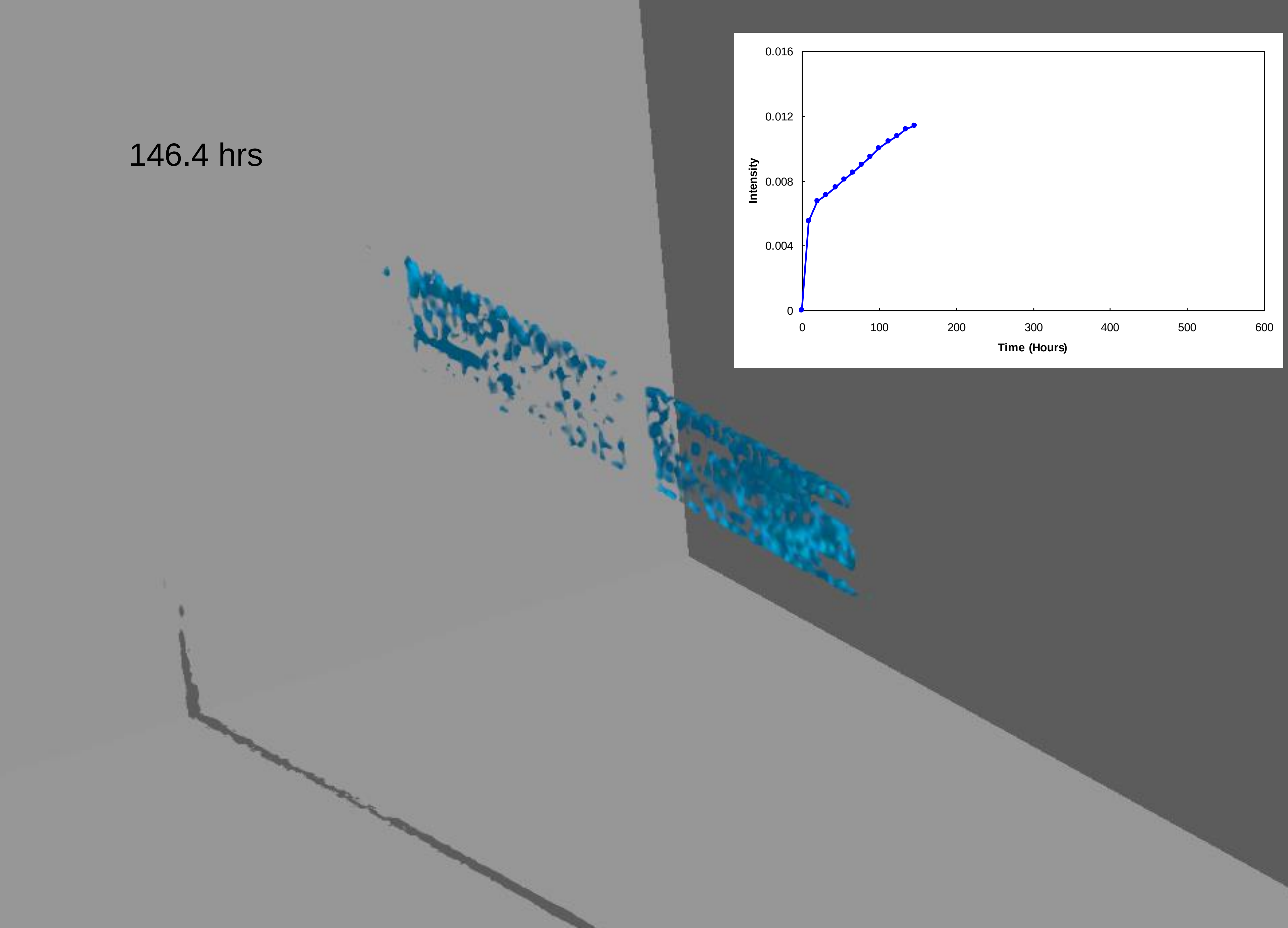
34b-10


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

34b-11

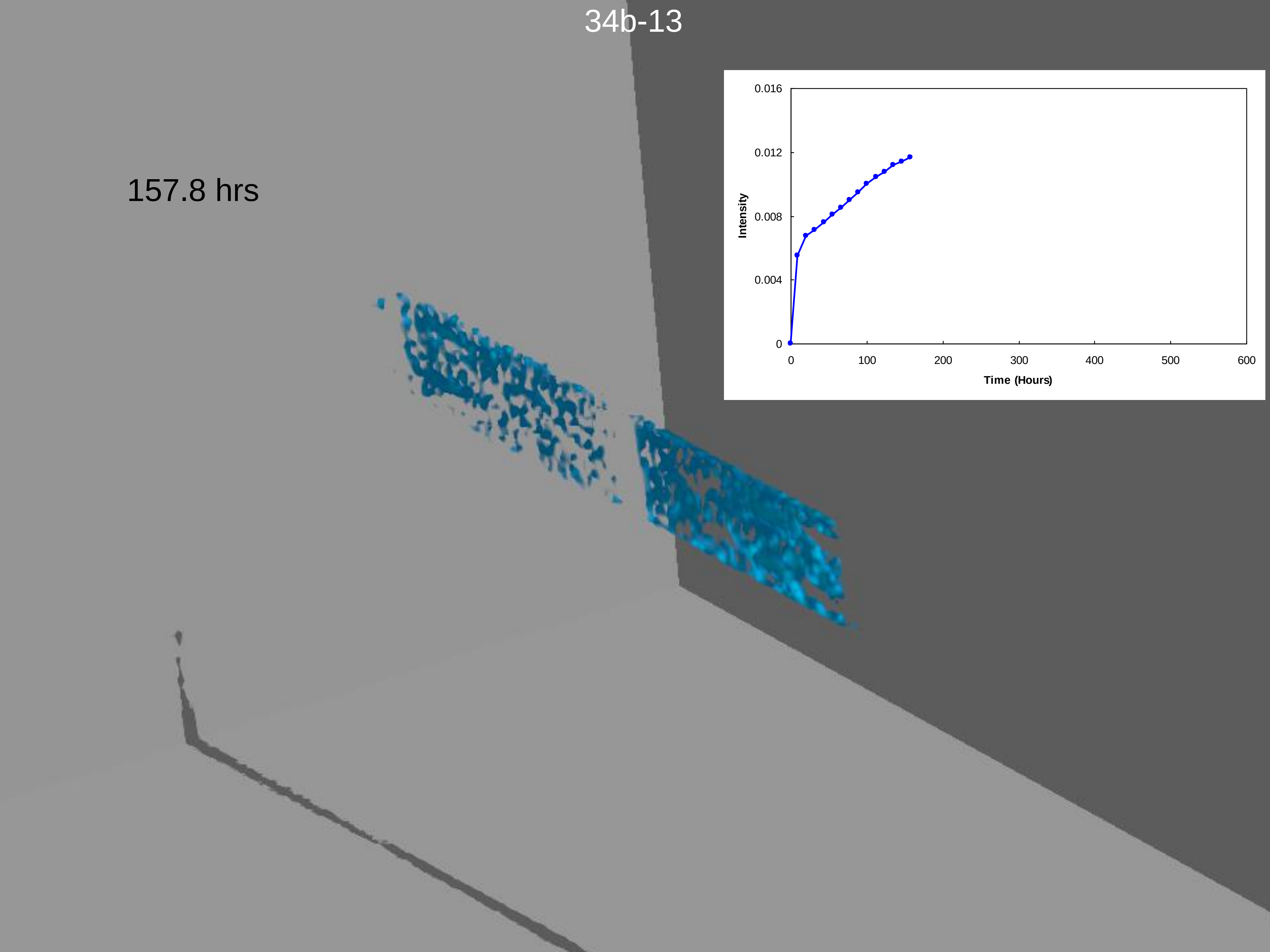

135.0 hrs
Intensity
0.016
0.012
0.008
0.004
0
0
100
200
300
400
500
600
Time (Hours)

34b-12


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

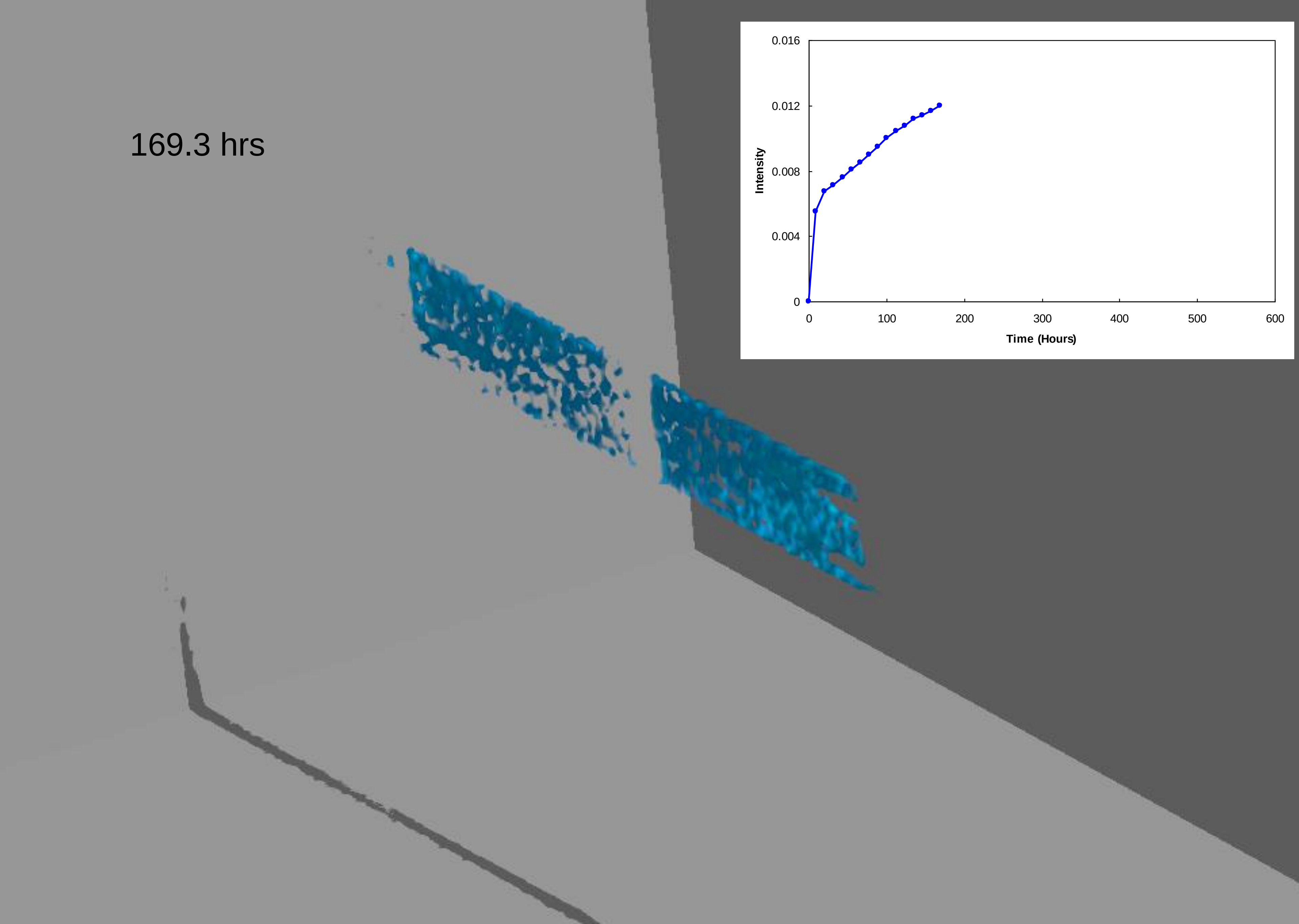
34b-13

157.8 hrs



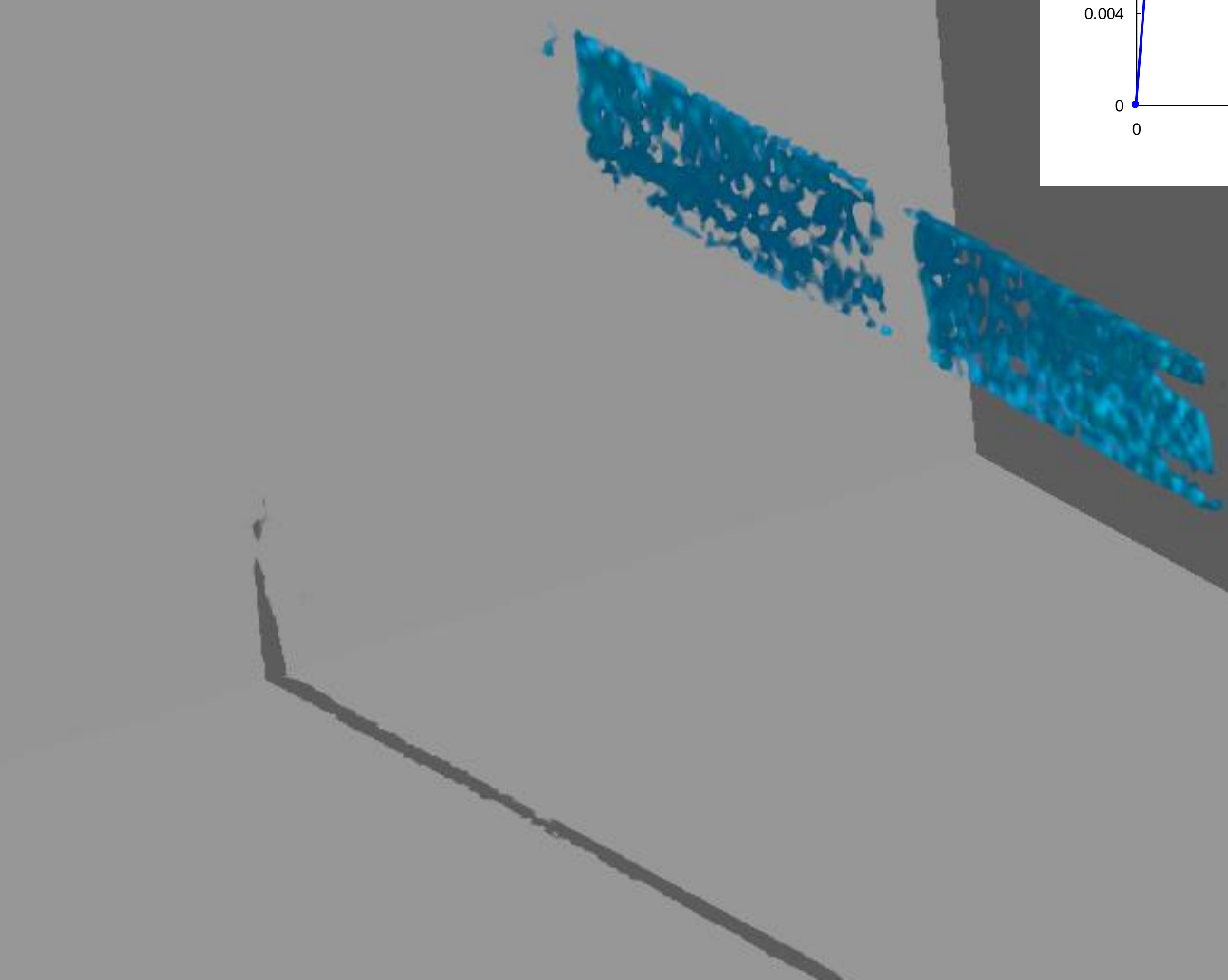
34b-14

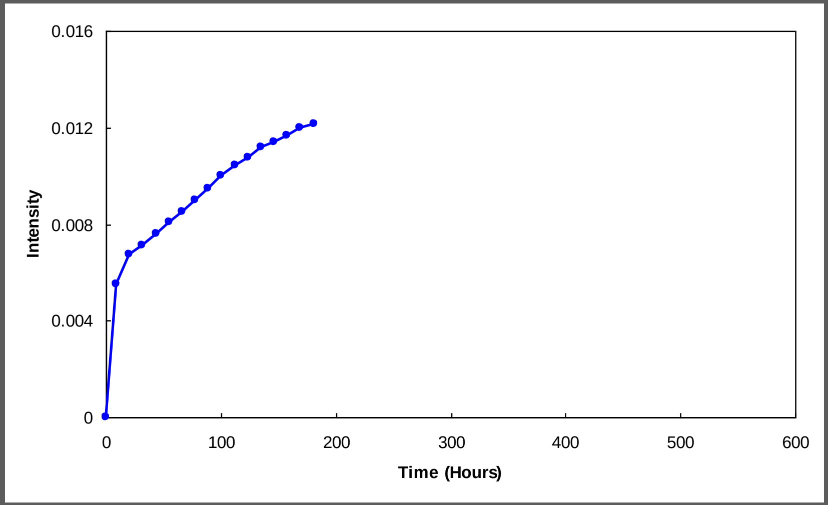
169.3 hrs



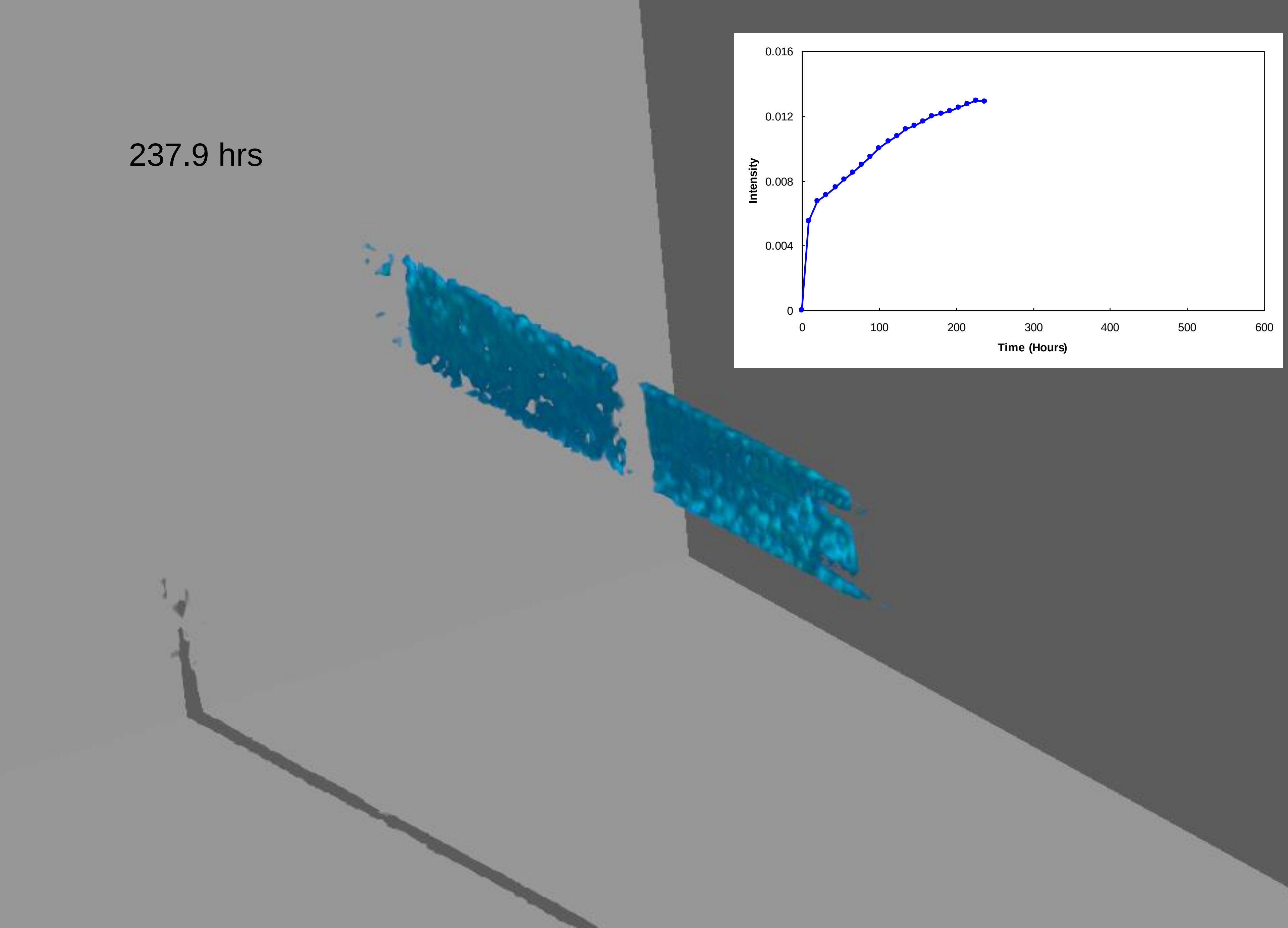
34b-15

180.7 hrs

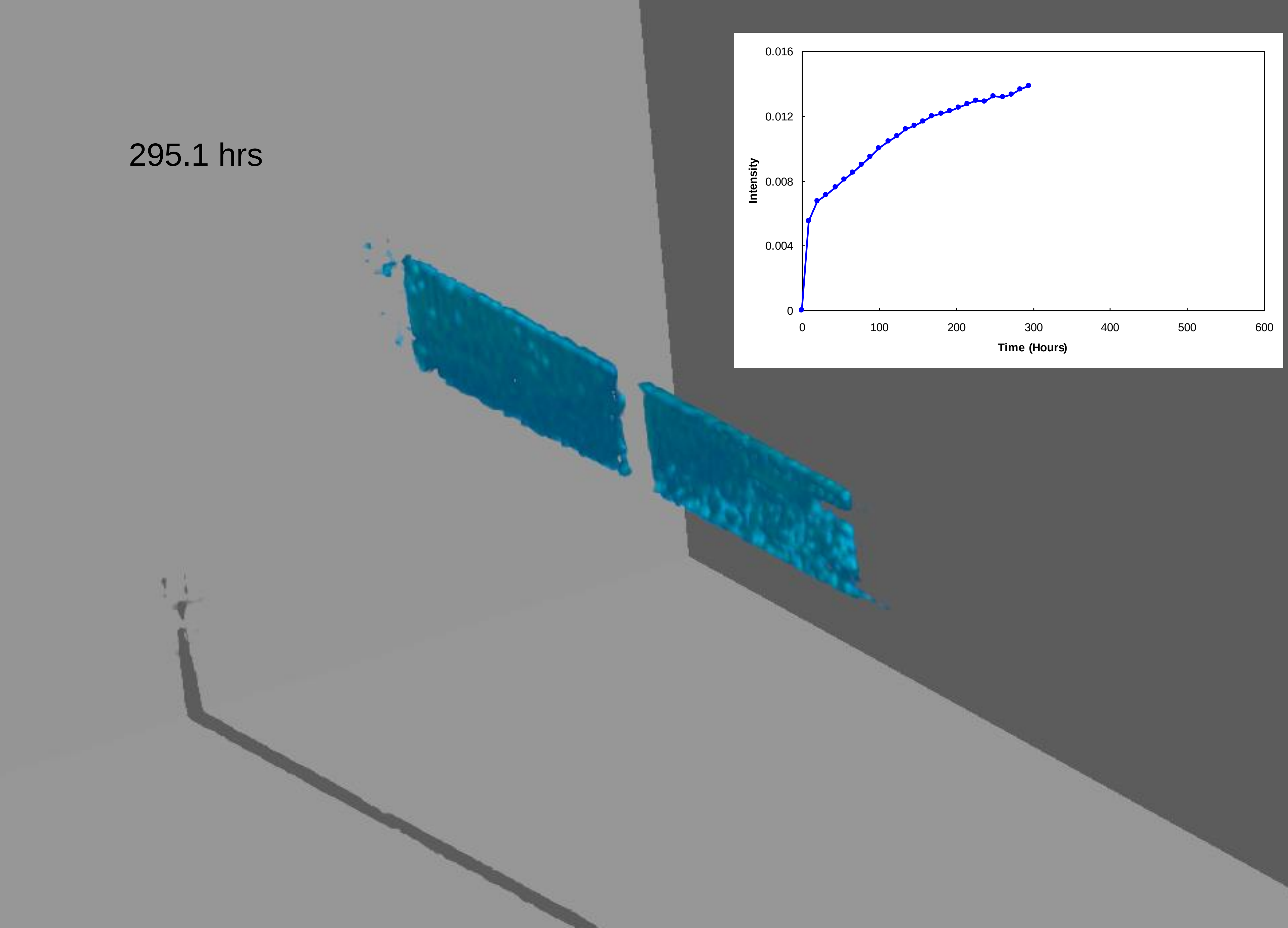


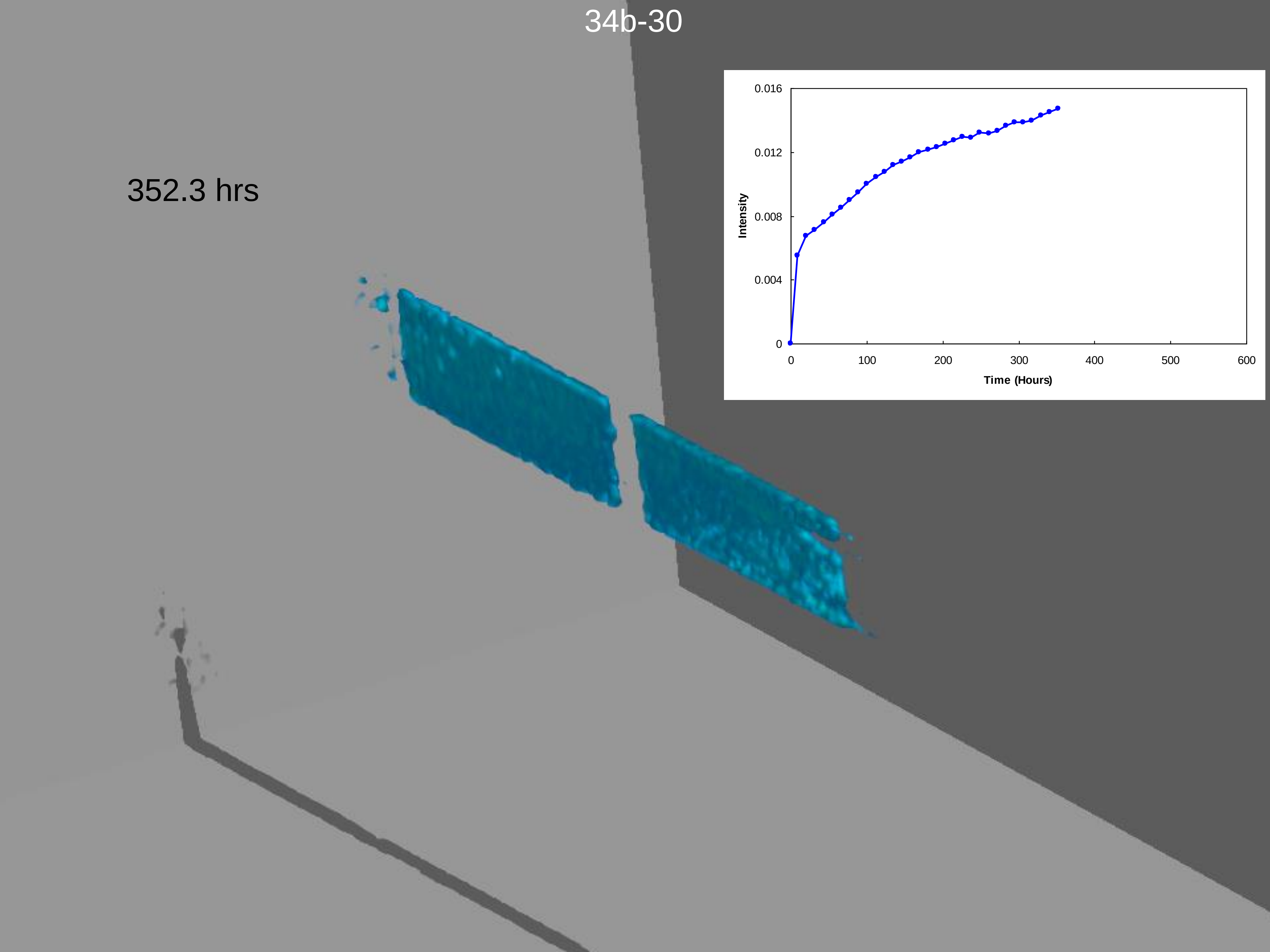


34b-20


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

34b-25

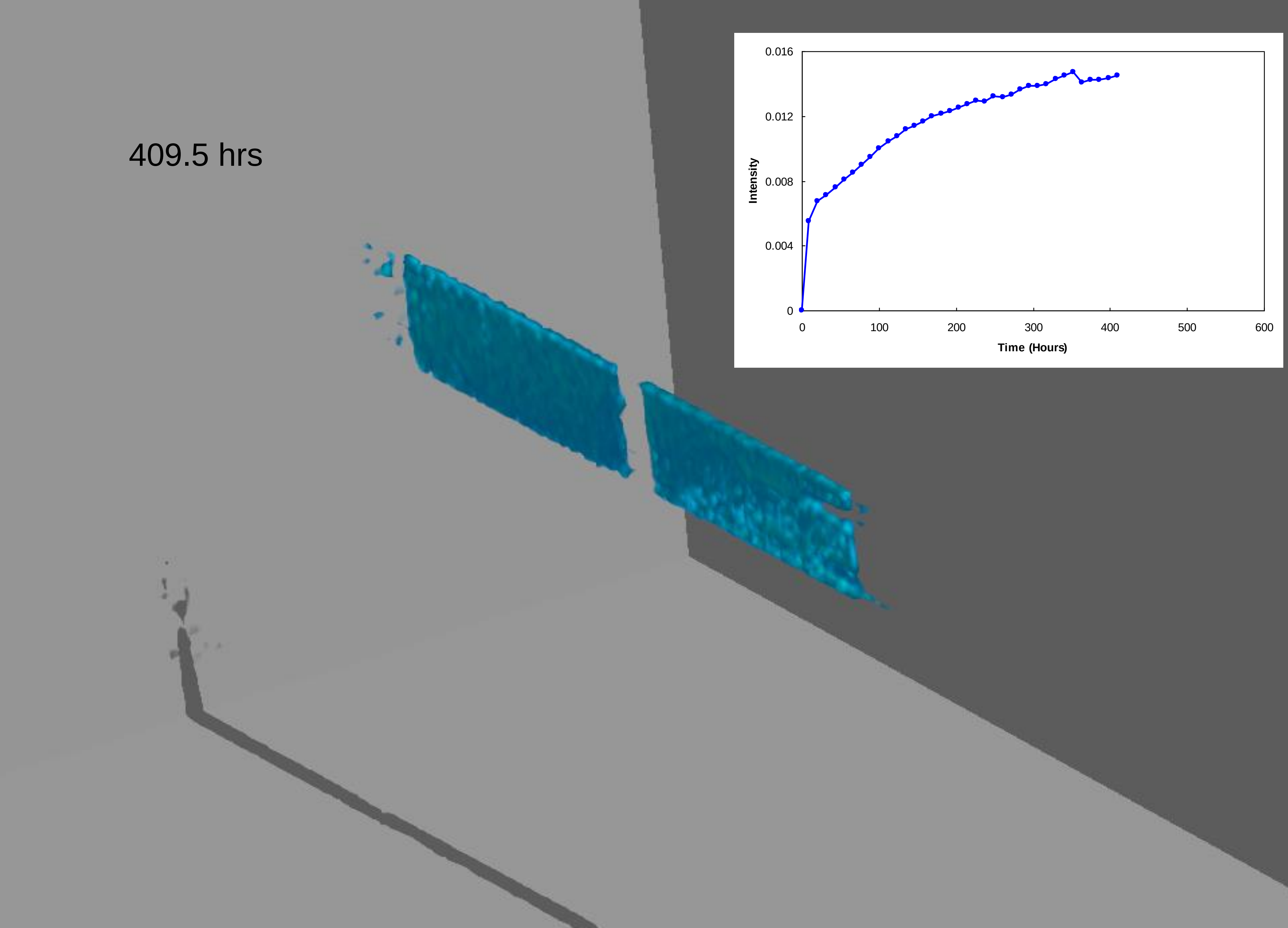

295.1 hrs
0.016
0.012
0.008
0.004
0
Intensity
0
100
200
300
400
500
600
Time (Hours)

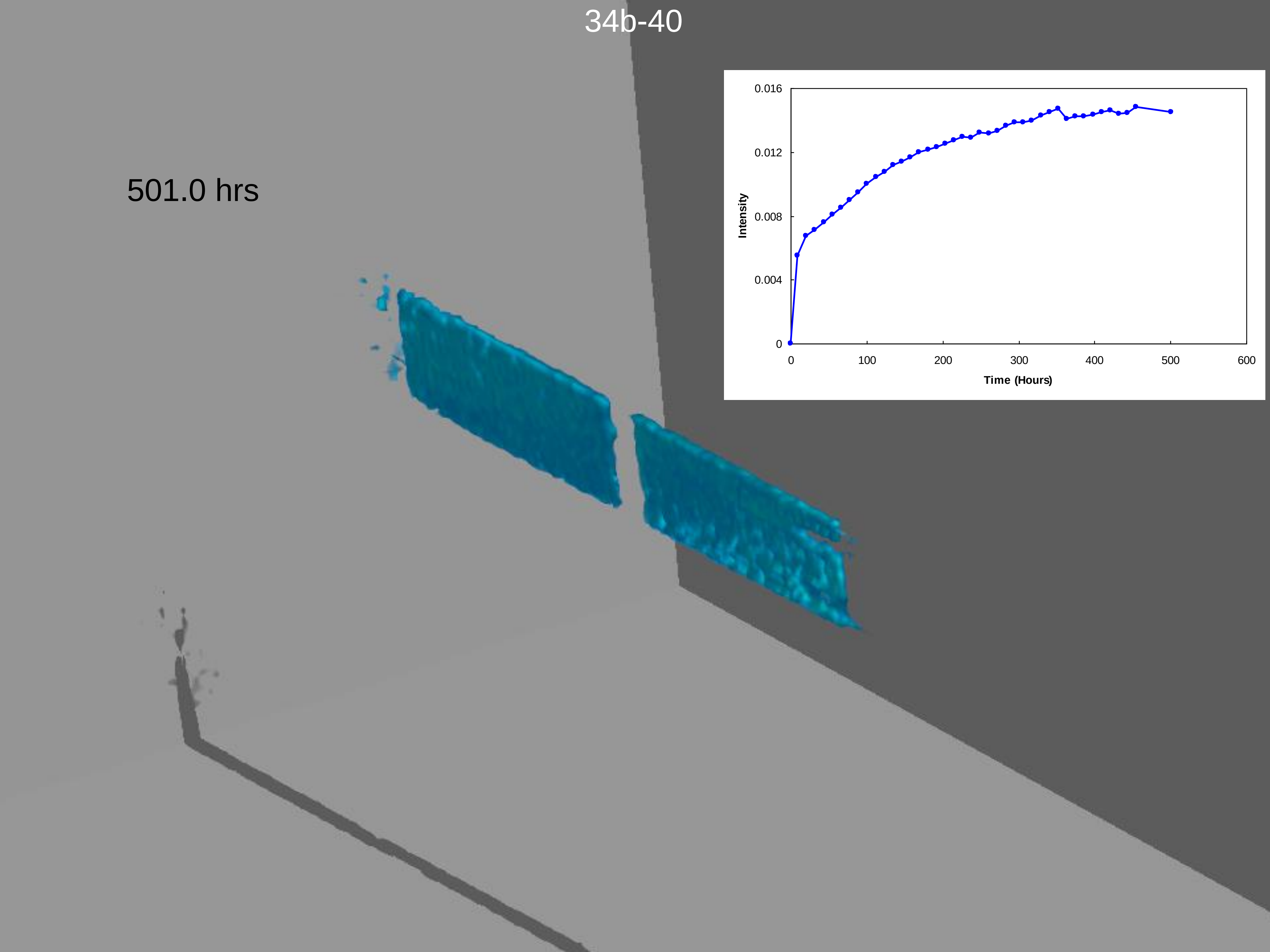


34b-30
352.3 hrs
0.016
0.012
0.008
0.004
0
Intensity
0
100
200
300
400
500
600
Time (Hours)

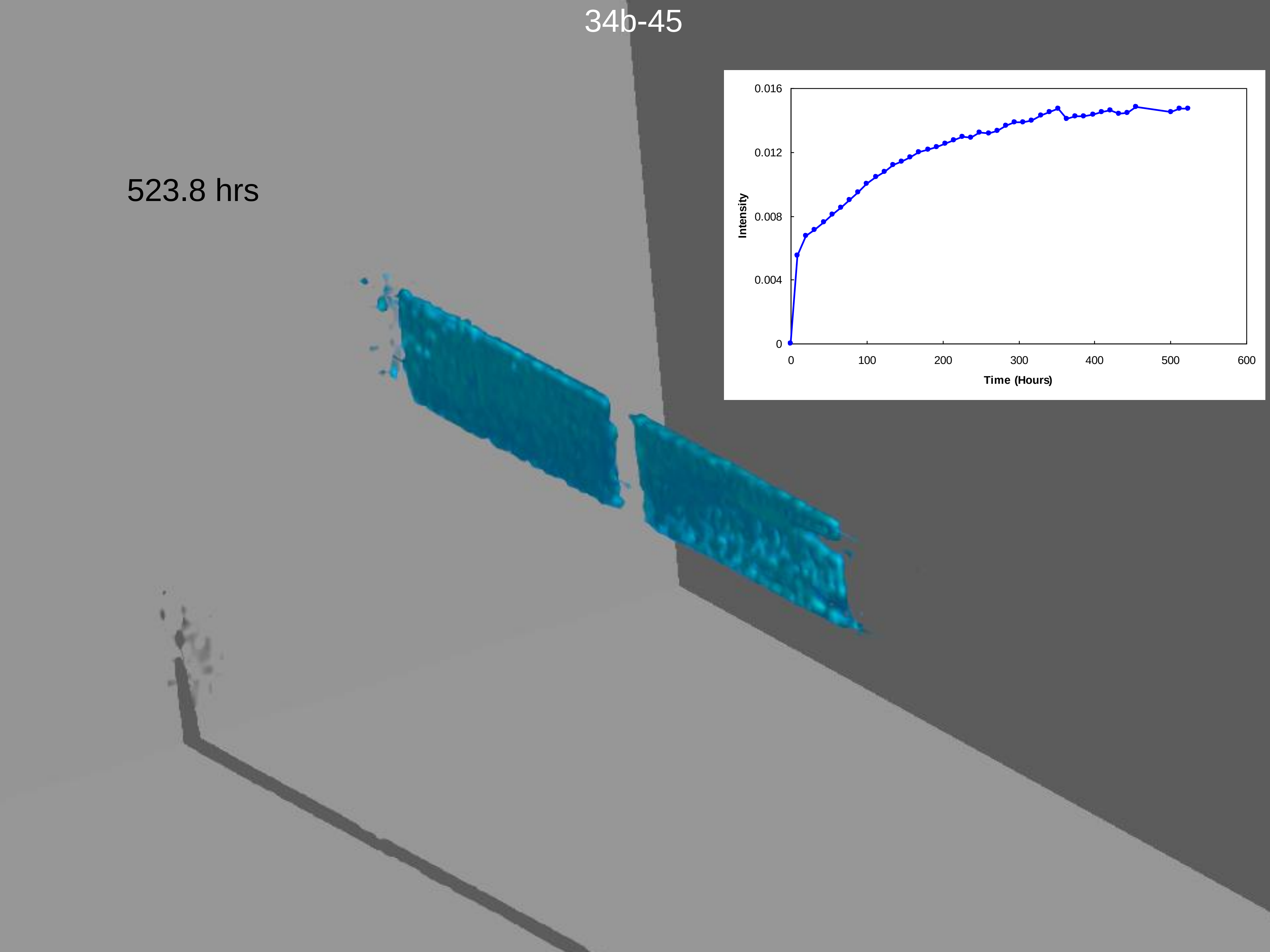
34b-35

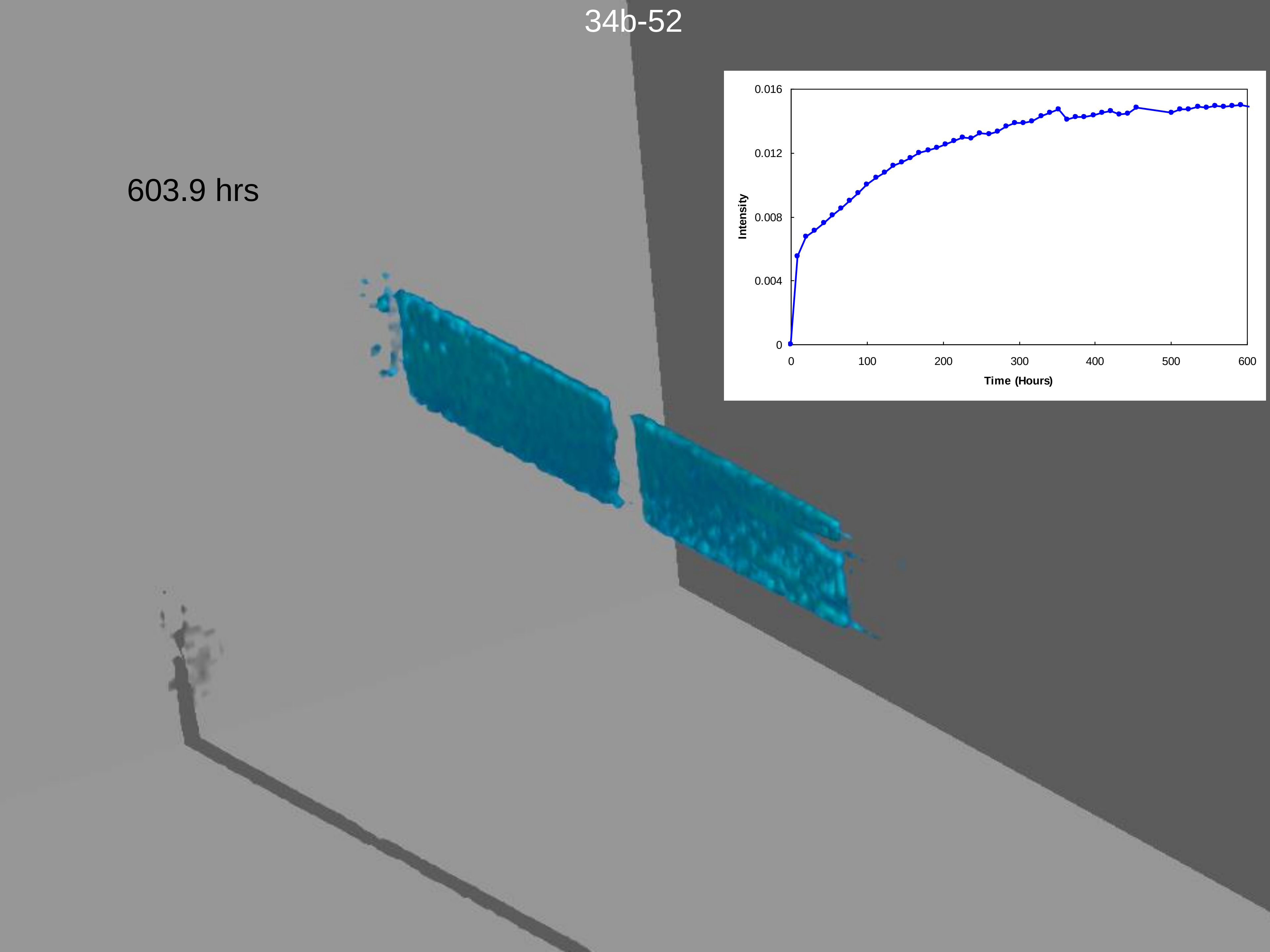
409.5 hrs



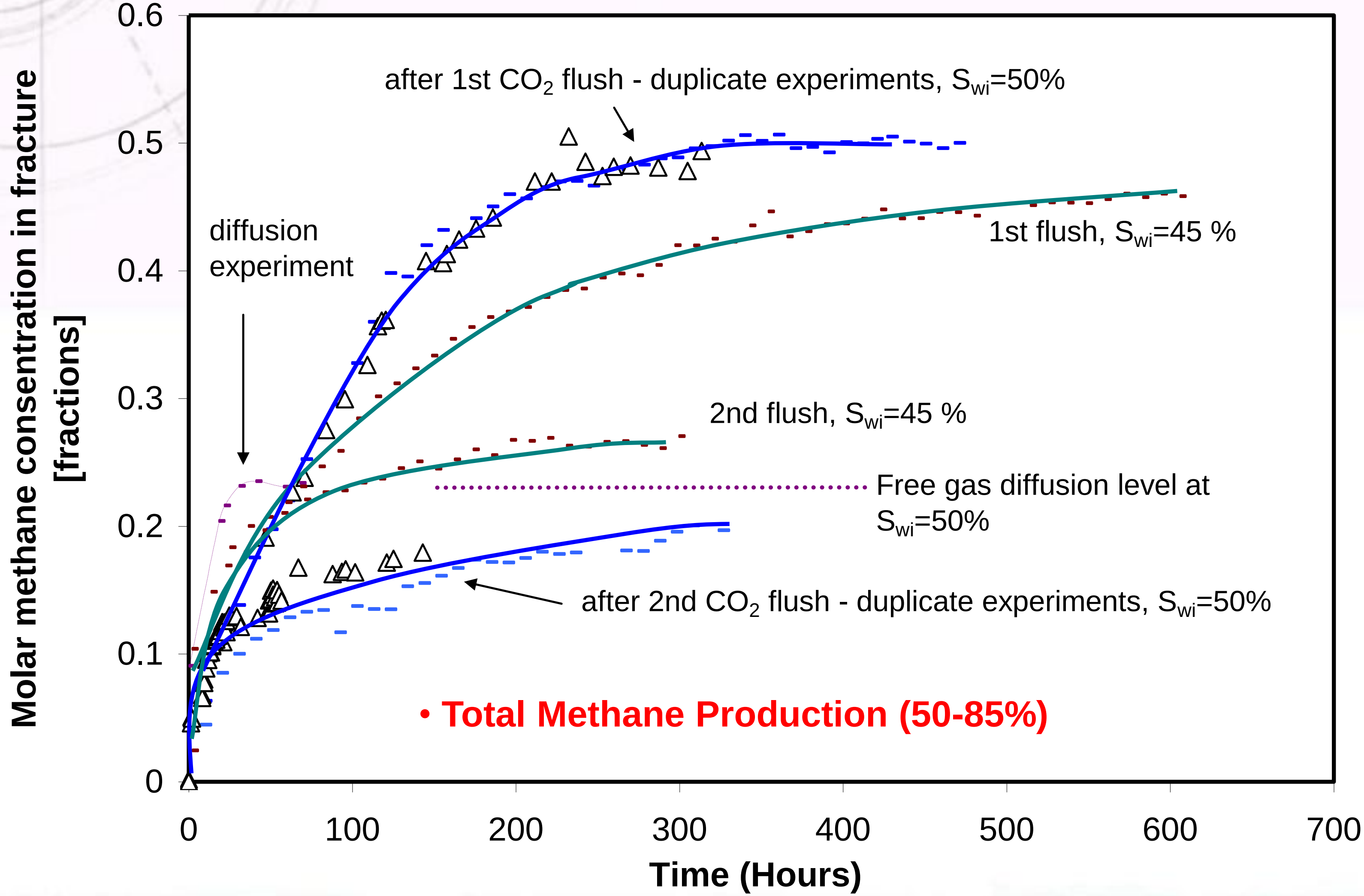


34b-40
501.0 hrs
Intensity
0.016
0.012
0.008
0.004
0
0
100
200
300
400
500
600
Time (Hours)


34b-45
523.8 hrs
Intensity
0.016
0.012
0.008
0.004
0
0
100
200
300
400
500
600
Time (Hours)


34b-52
603.9 hrs
0.016
0.012
0.008
0.004
0
Intensity
0
100
200
300
400
500
600
Time (Hours)

Methane Production



Thank you!