

Measuring Disaster

The magnitude of the BP oil spill

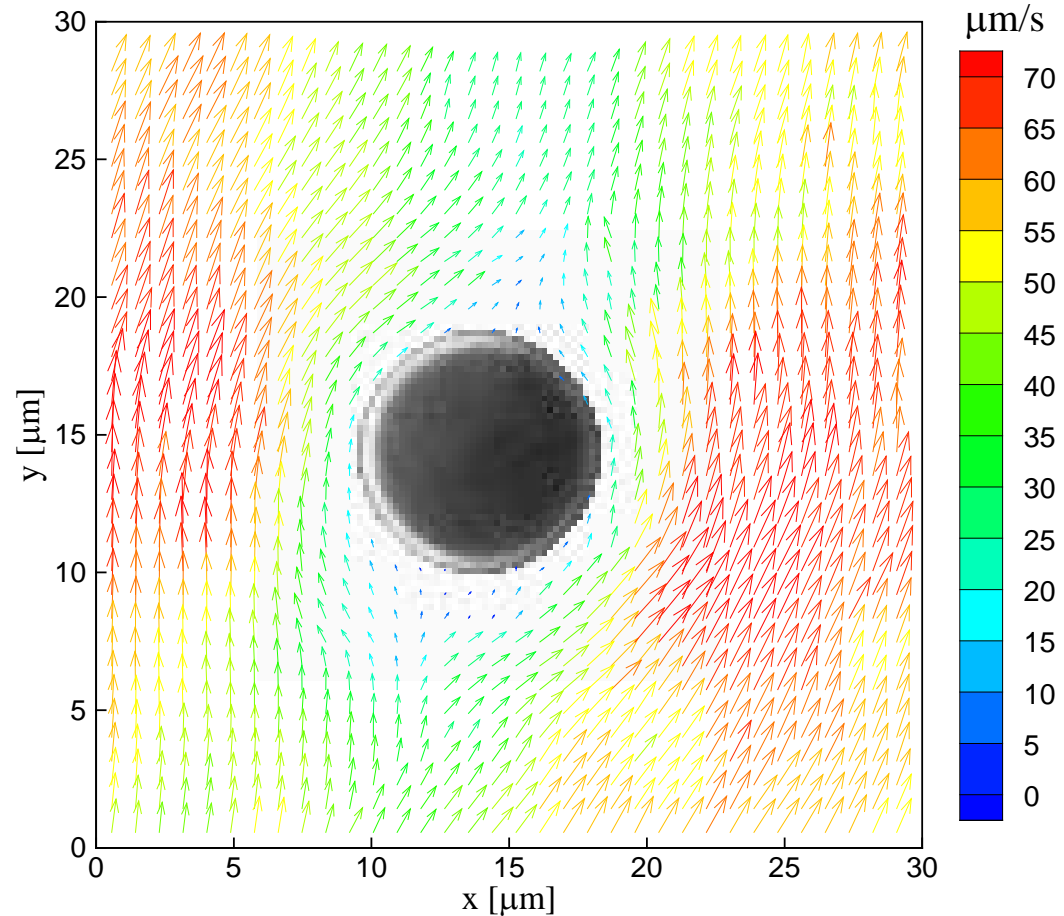
Steve Wereley

Professor of Mechanical Engineering
Birck Nanotechnology Center
Purdue University (USA)
wereley@purdue.edu

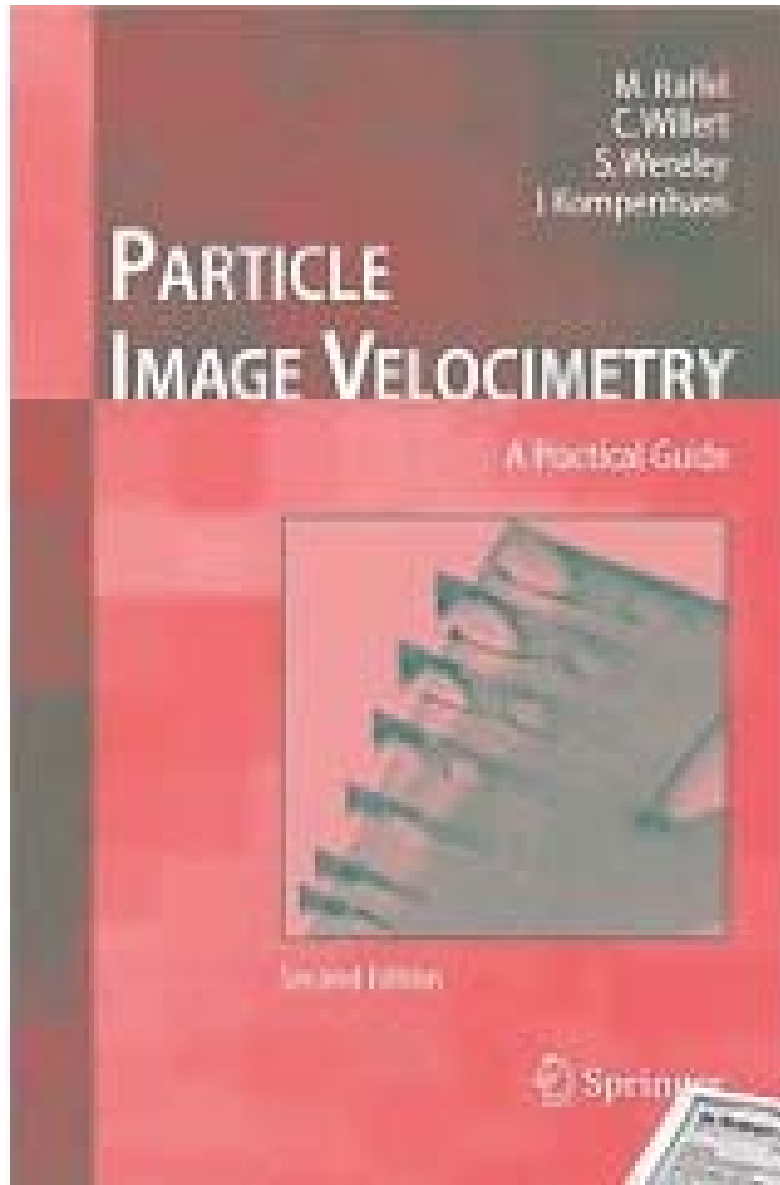
Flow Around a Red Blood Cell

S.T. Wereley and C.D. Meinhart, "Adaptive Second-Order Accurate Particle Image Velocimetry," Exp. Fluids (2001).

- Correlation-based interrogation
- Central difference image correction
- Mask technique
- Average correlation method
- Interrogation window: 16×16-pixel
- Spatial resolution: $3.5 \times 3.5 \times 2 \mu\text{m}^3$
25 femto liters



Fluid Mechanics Books



2nd edition of Springer
PIV book published 2007

2nd edition AH
Microfluidics book
published 2006

Micro/nano flow
phenomena explored
using practical examples

PIV Book currently 1st hit
on Google books

Image Based Flow Measurement

- Flows can be analyzed in a “stand off” manner using image analysis
- One technique called Particle Image Velocimetry (PIV)
 - 25 year history
 - Thousands of practitioners worldwide
- Particles carried by a transparent flow are tracked from frame to frame
 - Statistical methods
 - Accuracies as high as +/- 1%

Deepwater Horizon Accident



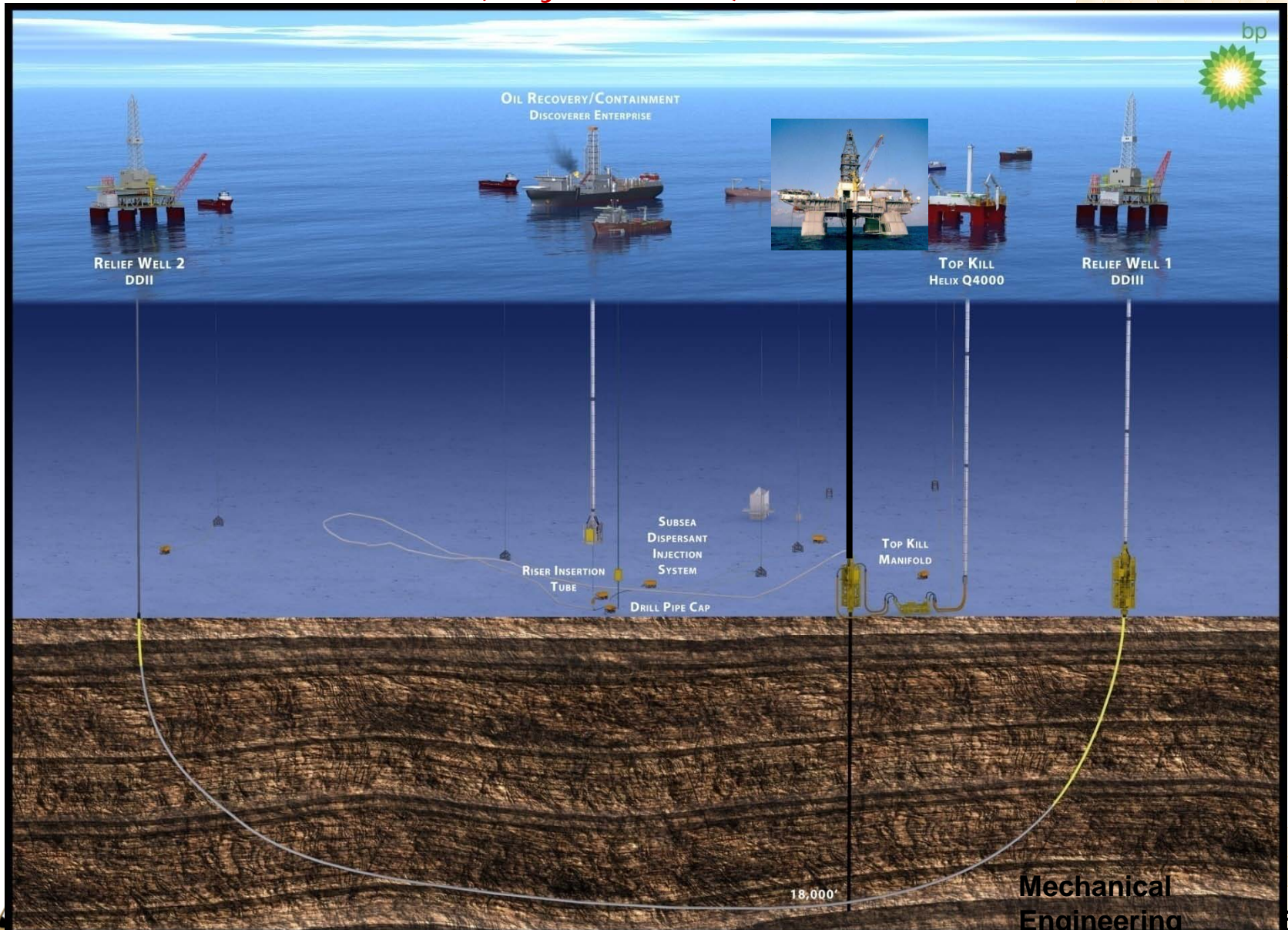
Semi-submersible
drilling vessel

April 20th Blow out
11 people died (presumed)
36 hour fire
Vessel sank

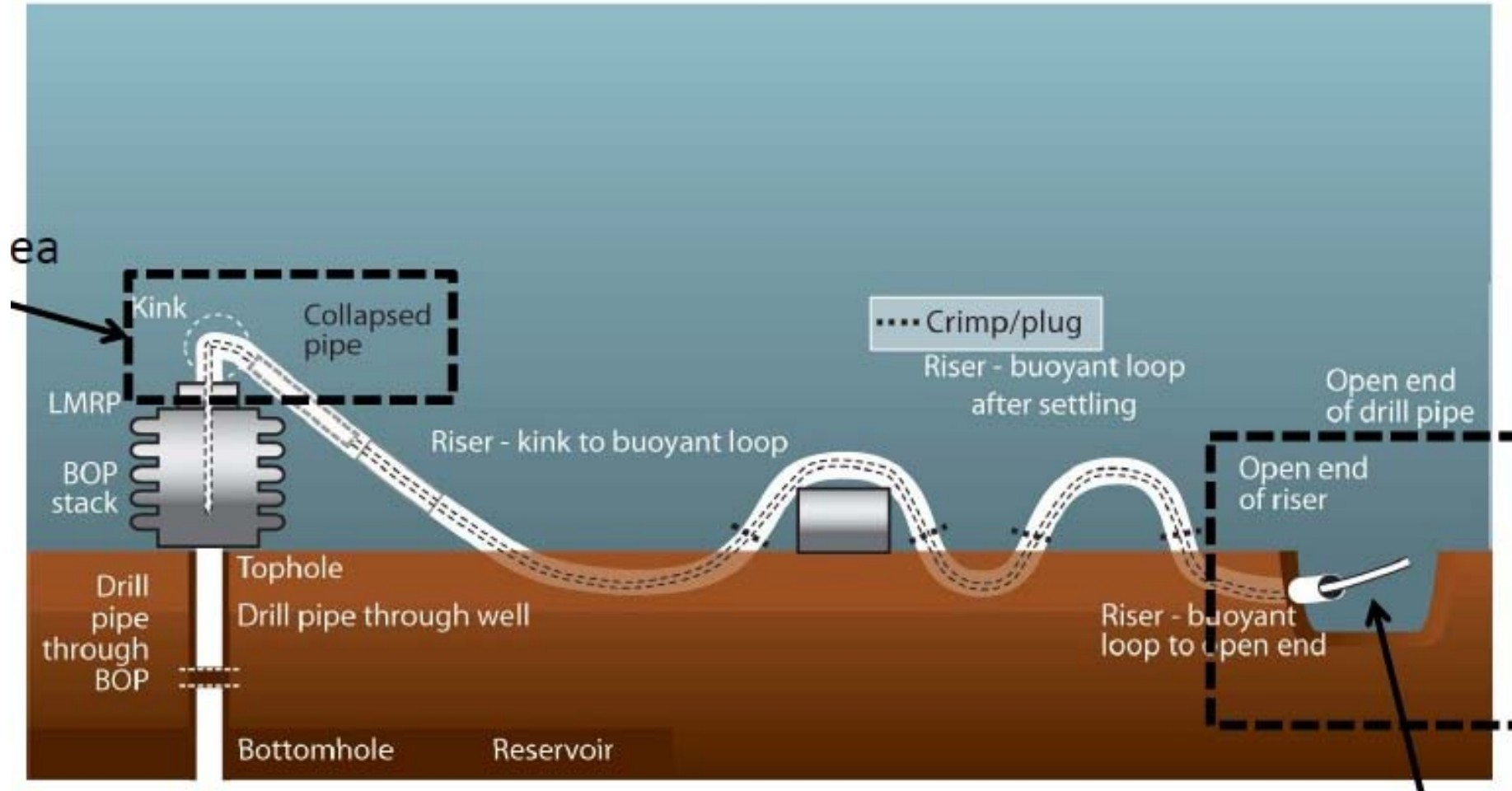


Intervention operations

(May 26, 2010)



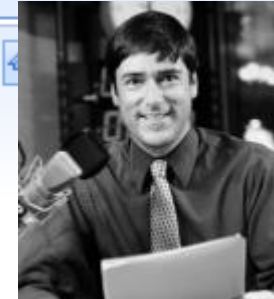
Two oil spill locations



From: Wereley, Steven T.
To: Bross, Kristina K
Cc:
Subject: FW: oil pipes and PIV

Sent: Thu 5/13/2010 4:11 PM

From: Richard Harris [mailto:RHarris@npr.org]
Sent: Thursday, May 13, 2010 1:27 PM
To: Wereley, Steven T.
Subject: oil pipes and PIV



Hi, Dr. Wereley,

I'm trying to find folks who can calculate the flow rate from the BP pipe on the ocean floor. They posted a video of it online yesterday at...

<http://www.dvidshub.net/>

I understand PIV is the perfect tool for this problem. Since you literally wrote the book about it, I'm coming to you. Could you estimate the flow depicted in this video? I believe (but am still trying to confirm) that the pipe diameter is 21 inches.

Please call when you can.

Thanks.

Richard Harris

First Video of Spill Released

Crater_plume_gassing_11_may_2010_2333.wmv



Physical Reasoning

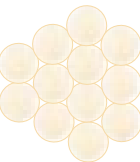
- To answer the flow rate question, need to know two things
 - How fast is it moving?
 - $V_{avg} = \text{distance/time}$
 - How much is there?
 - $Q = V_{avg} * A_{CS}$

Manual Feature Tracking

Not rocket science—identify features in the image and see where they go as time elapses



Observed displacement: 11.7 pixels



Gently Enhanced Images

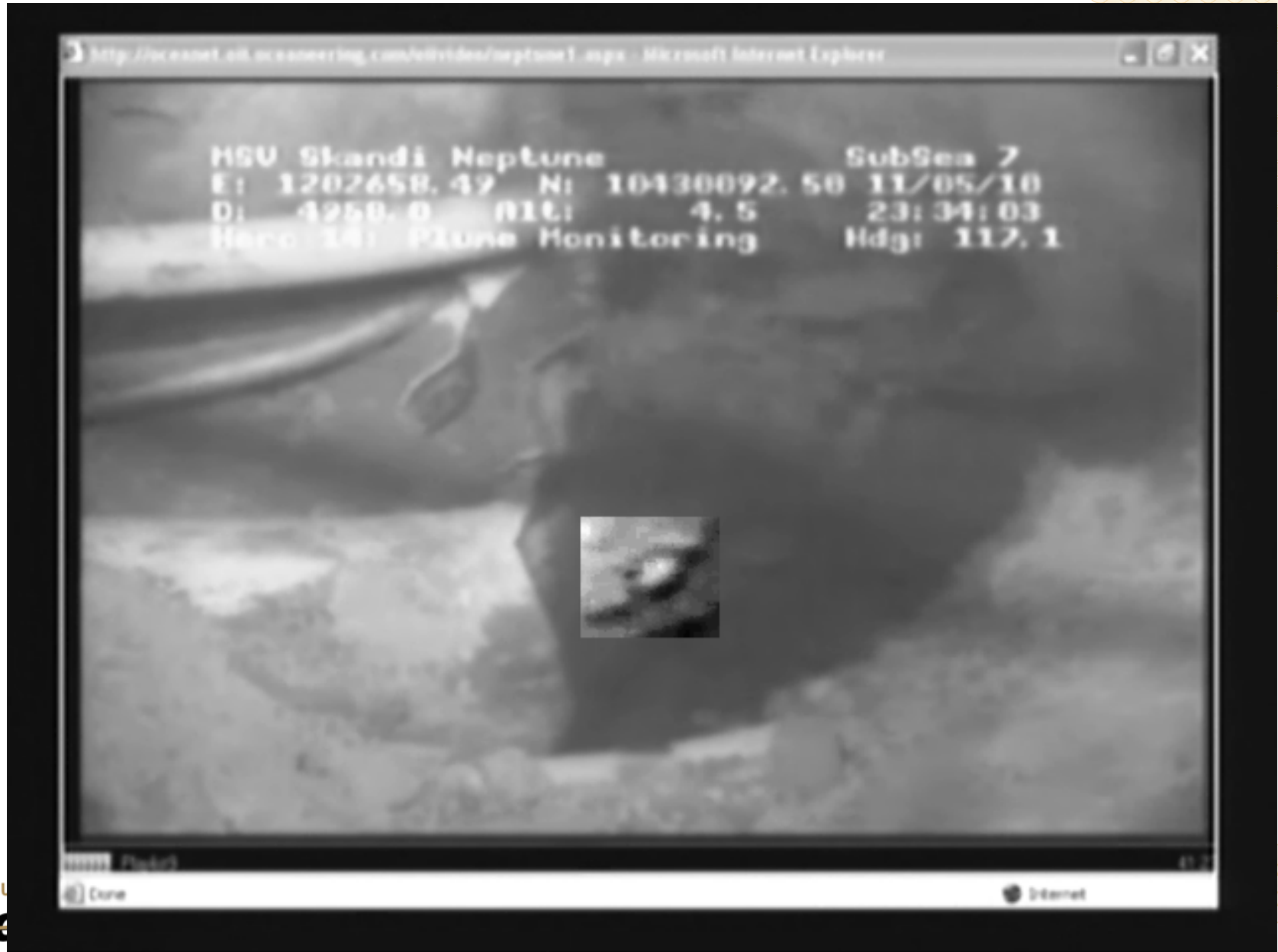


Now it's your turn

- You have 5 minutes to work through the hand out and answer a few questions about calculating the flow rate
- To put some added incentive to work accurately and quickly, the last group I did this with was Mrs. Miller's 4th/5th grade class at Burnett Creek Elementary



Gently Enhanced Images



Survey question #1

- How far do you estimate the oil jet is moving between two adjacent video frames?
- A. Less than 0.89 in
 - B. 0.89-1.42 in
 - C. 1.42-2.12 in
 - D. 2.12-2.66 in
 - E. More than 2.66 in

Survey question #2

- What do you estimate the total flow of all hydrocarbons (oil+gas) out of the pipe is?

(Note: 1 gal = 231 in³ and 1 bbl = 42 gal)

- A. 0-35,000 bbl/day
- B. 35,000-56,000 bbl/day
- C. 56,000-84,000 bbl/day
- D. 84,000-105,000 bbl/day
- E. More than 105,000 bbl/day

Survey question #3

- Given the information available and the calculations you just made, how likely is it that the actual oil flow rate is 5,000 bbl/day?
 - A. Inconceivable
 - B. Highly unlikely
 - C. Unlikely
 - D. Possible
 - E. Just hoping my BP share price goes up

Survey question #4

- What is your highest completed degree?
 - A. High school (*current undergrads*)
 - B. Bachelors (*current MS students*)
 - C. Masters (*current PhD students*)
 - D. PhD (*current post doc*)
 - E. Professor (*i.e. way too much education*)

Survey question #5

- What is your engineering preparation with regards to fluid mechanics?
 - A. None
 - B. General engineering
 - C. Some fluid mechanics (*i.e. interest or classes*)
 - D. Fluid mechanics specialist (*i.e. thesis project or degree in fluids*)

Computer Analysis (PIV)



Calculated displacement: 10.2 pixels

Professional looking mathematics...



$$10.17 \text{ pixels/s} \rightarrow \frac{381 \text{ mm}}{257} = 124 \text{ pix}$$

$$\begin{array}{r} 957 \\ 890 \\ \hline 0.067 \text{ sec} \end{array}$$

$$V = 10.17 \text{ pix/frame} \times 0.067 \text{ s} \times \frac{21 \text{ in}}{124 \text{ pix}} = 25.7 \text{ in/sec}$$

$$Q = VA = 25.7 \text{ in/sec} \times \frac{\pi (20 \text{ in})^2}{4} = 8904 \frac{\text{in}^3}{\text{sec}} = 38.5 \text{ gal/sec}$$

Temodal
temozolomid



$$Q = 0.918 \text{ barrels/sec} = 7935 \text{ barrels/day} = 70000$$

~~AR Schwarz 213~~

~~Frank 49~~

~~Charlie Moore 212 487~~
202 2


Iva Zarnich BBC

Temodal
temozolomid

Extra line breaks in this message were removed.

From: Bross, Kristina K
To: Wereley, Steven T.
Cc:
Subject: FW: oil pipes and PIV

Sent: Tue 6/15/2010 11:14 PM

Message |  image003.jpg (1 KB)

From: Wereley, Steven T.
Sent: Thursday, May 13, 2010 4:11 PM
To: Bross, Kristina K
Subject: FW: oil pipes and PIV

Next

Previous

Richard Harris from NPR's Talk of the Nation called today and asked if I'd take a look at some video just released that shows the oil flowing out of the blown up oil rig pipe in the gulf. Someone suggested to him that PIV was just the ticket for measuring this flow. I spent about two hours making a calculation and figured that 80,000 barrels a day is flowing into the gulf and not 5,000 as people have been saying. He just interviewed me for Talk of the Nation. I'm not sure when they'd air this but I'll ask him if I don't hear anything from him by tomorrow.

Cool...

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web page: <http://engineering.purdue.edu/~wereley>

From: Richard Harris [mailto:RHarris@npr.org]



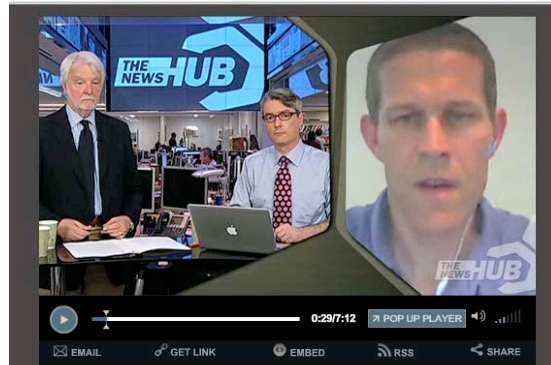
800+ major media

placements and counting...

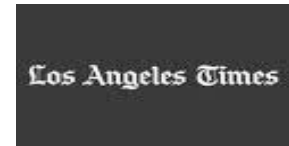
From CNN and The Wall Street Journal to Al-Jazeera and BusinessWeek, Professor Wereley analysis has connected Purdue to the world on the BP oil spill in the Gulf



ALJAZEERA



Oil Flow Estimates Are Significantly Boosted 6/10/2010 5:56:22 PM
As many as 50,000 barrels of oil per day may have flowed into the Gulf before it was partly contained on June 3, the U.S. Geological Survey says. Purdue University's Steven Wereley, a key member of the group making the assessment, talks with WSJ's Robert Lee Hoiz about the new flow estimates.



Better looking math

suitable for presentation to Congress

- Find average plume velocity

$$10.2 \frac{\text{pixels}}{\text{frame}} \times \frac{1 \text{ frame}}{0.067 \text{ sec}} \times \frac{21 \text{ in}}{124 \text{ pixels}} = 25.8 \frac{\text{in}}{\text{sec}}$$

- Multiply by cross-sectional area to find volume flow rate

$$25.8 \frac{\text{in}}{\text{sec}} \times \frac{\pi}{4} \times (20 \text{ in})^2 = 8105 \frac{\text{in}^3}{\text{sec}}$$

- Convert to barrels per day

$$8105 \frac{\text{in}^3}{\text{sec}} \times \frac{60 \times 60 \times 24 \text{ sec}}{\text{day}} \times \frac{1 \text{ gal}}{231 \text{ in}^3} \times \frac{1 \text{ bbl}}{42 \text{ gal}} = 72179 \frac{\text{bbl}}{\text{day}}$$

How did this agree with others?

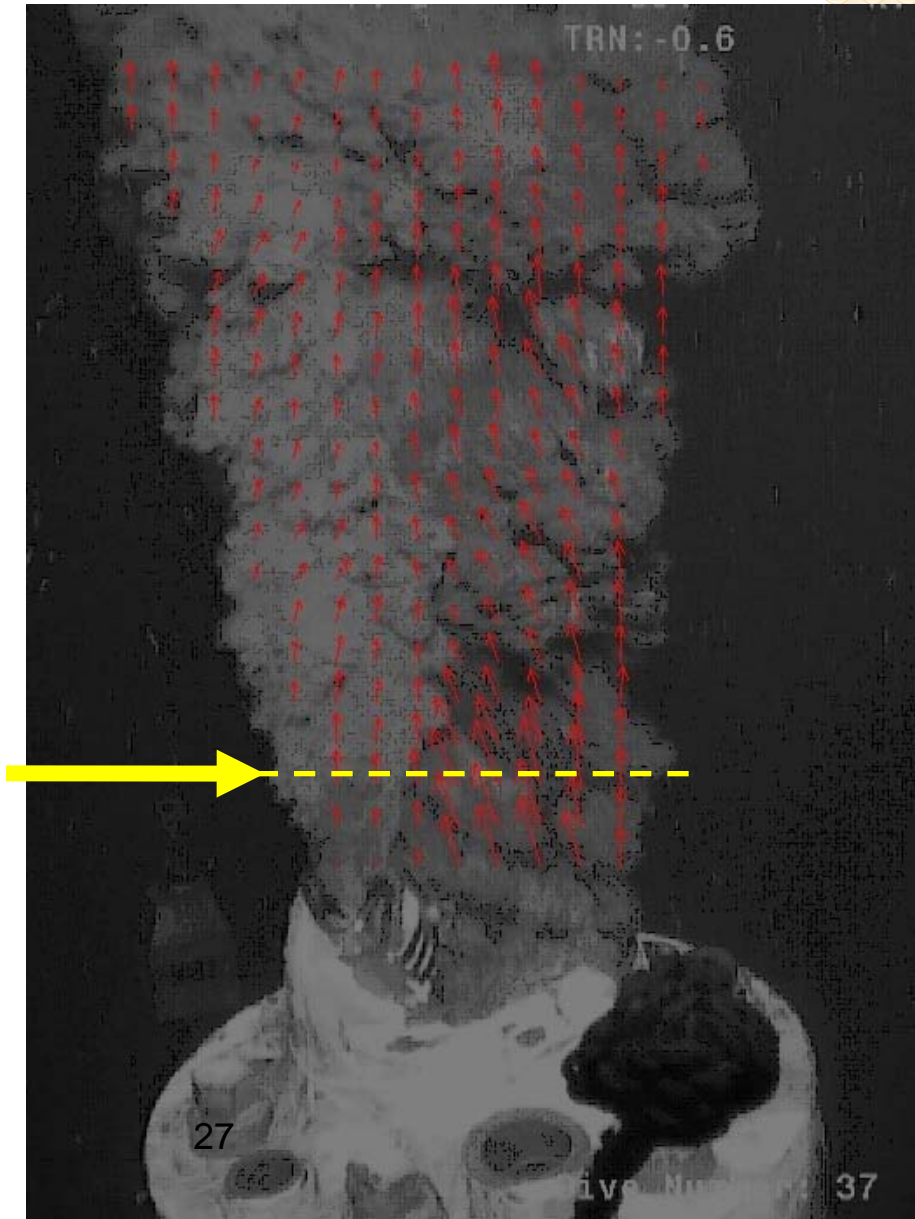
- Surface analysis
 - BP: 5,000 bbl/day
 - MacDonald (FSU): 25,000 bbl/day
- Video analysis
 - Chang (UCB): 20,000-100,000 bbl/day
 - Crone (Columbia): 20,000-100,000 bbl/day
 - Wereley (Purdue): 56,000-84,000 bbl/day
- Comparison
 - All outsider estimates higher than BP's
 - Good overlap among outsider estimates

BP's Response

- Press release May 21
 - The rate of flow from the riser is determined in a number of ways and by a number of variables. For instance, while the original riser was 19.5 inches in diameter prior to the Deepwater Horizon accident, damage sustained during the accident distorted the diameter at the end of the pipe by about 30 per cent. In addition, a drill pipe currently trapped inside the riser has reduced the flow area by an additional 10 per cent. **Thus, some third party estimates of flow, which assume a 19.5 inch diameter, are inaccurate.** As well, there is natural gas in the riser. Data on the hydrocarbons recovered to date suggests that the proportion of gas in the plume exiting the riser is, on average, approximately 50 percent.

PIV results

Velocity calculated here
Avg disp 8.27 pixels

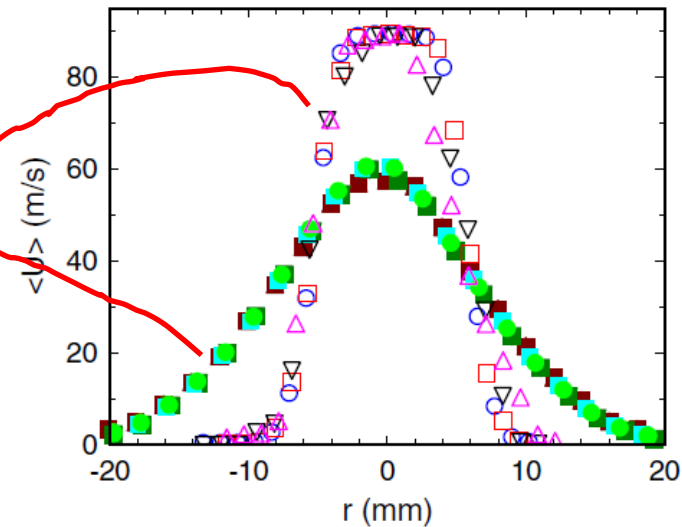
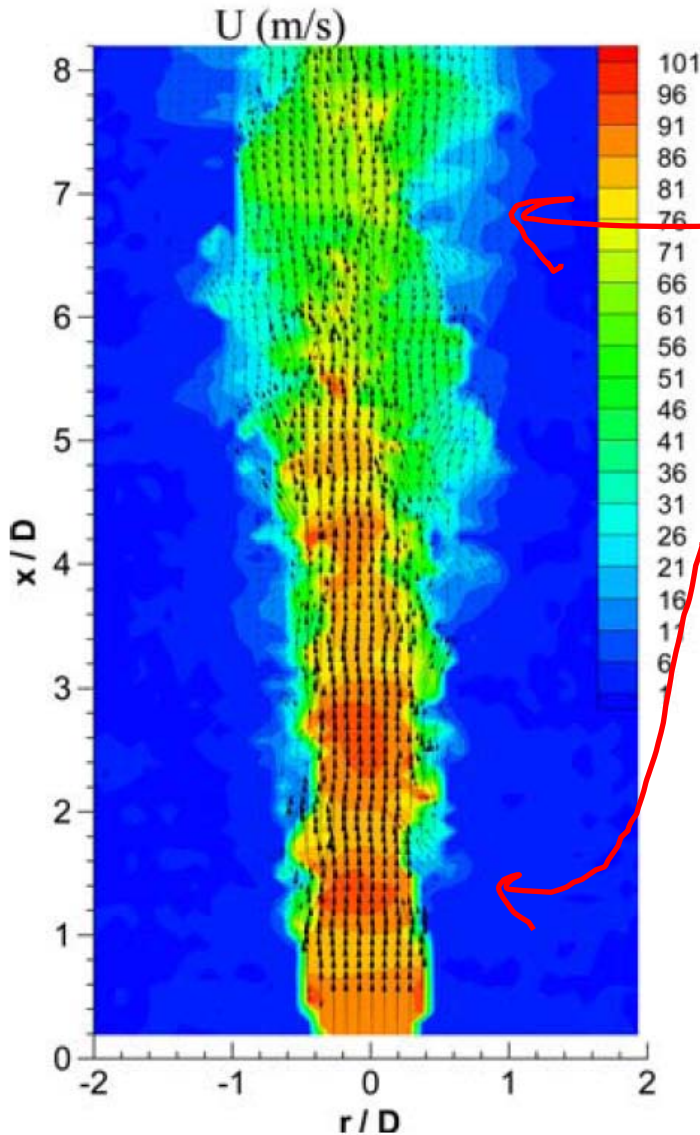


Timeline

- Apr 20: Blow out
- May 13: Wereley and others make independent flow calculations
- May 19: Wereley appears before Rep Markey's committee
- May 20: Adm Allen creates *Flow Rate Technical Group* (Wereley member)
- May-June-July: Several steadily increasing flow rate estimates as better video is released
- Aug 2: Final press release
 - Flow rate initially 62->53 kbbl/day
 - Total oil volume release 4.9 Mbbl/day

Limitations/Jet flow physics

Mi, et al., Exp fluids, 2007



- PIV can normally “see through” flow to allow integrating velocity to get flow rate
- Crude oil is opaque

Need New Experiments

- We need to know how the speed of visible outer flow structures relates to average jet speed
 - Series of lab experiments on opaque jets to assess this relationship
 - Potentially multiphase
- Crone, et al. (2008) had a good first cut
 - Analyzing these images I get speed ratio of 1.76
 - Images too small (~ 300 pix)
 - Reynolds numbers not matched



Impact

- One Exxon Valdez spill *every 4.5 days*
- Total volume spilled 4.9 million barrels
 - *19 times* Exxon Valdez spill



Working groups

FRTG
June 13
Seattle

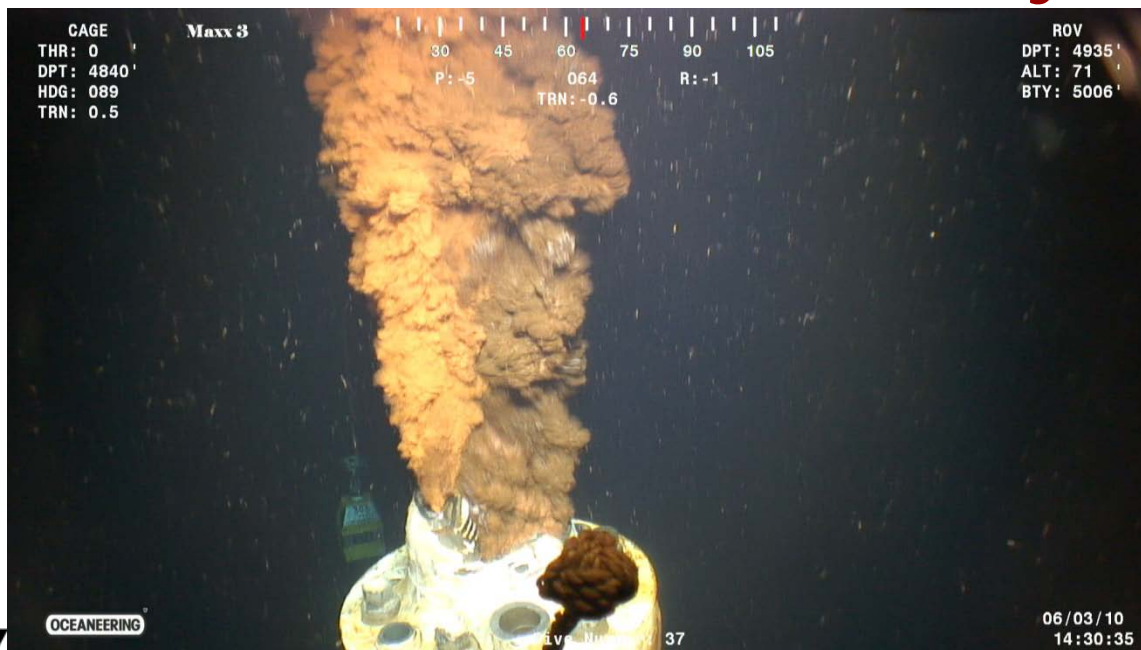


Sec Chu and Salazar
June 14, Washington, DC



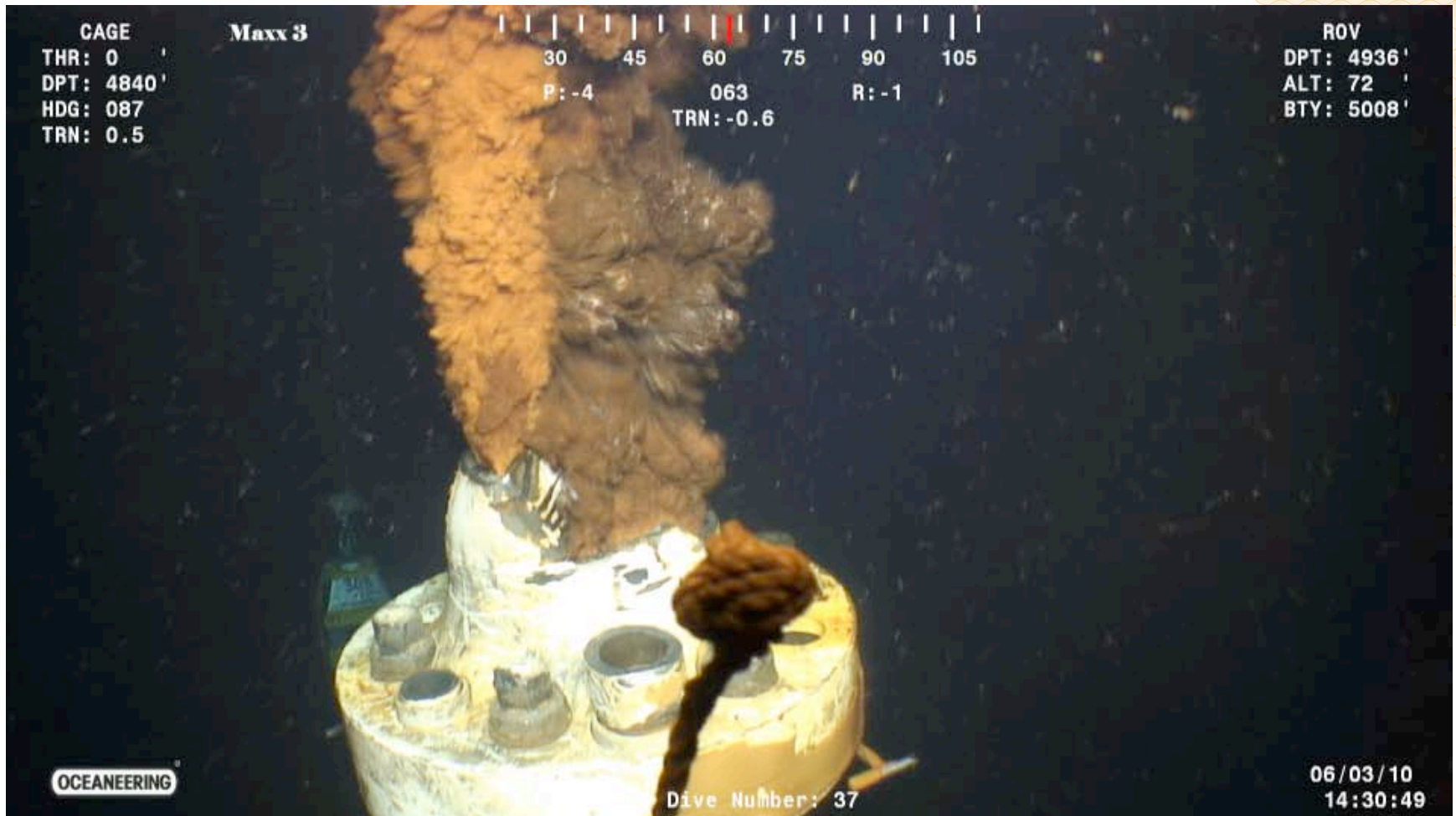
Post Riser Cut (June 3)

- FRTG examined new videos
 - (35-50 kbbl/day)
- Woods Hole used sonar method
- DOE used pressure measurements
- New estimate: 35-60 kbbl/day

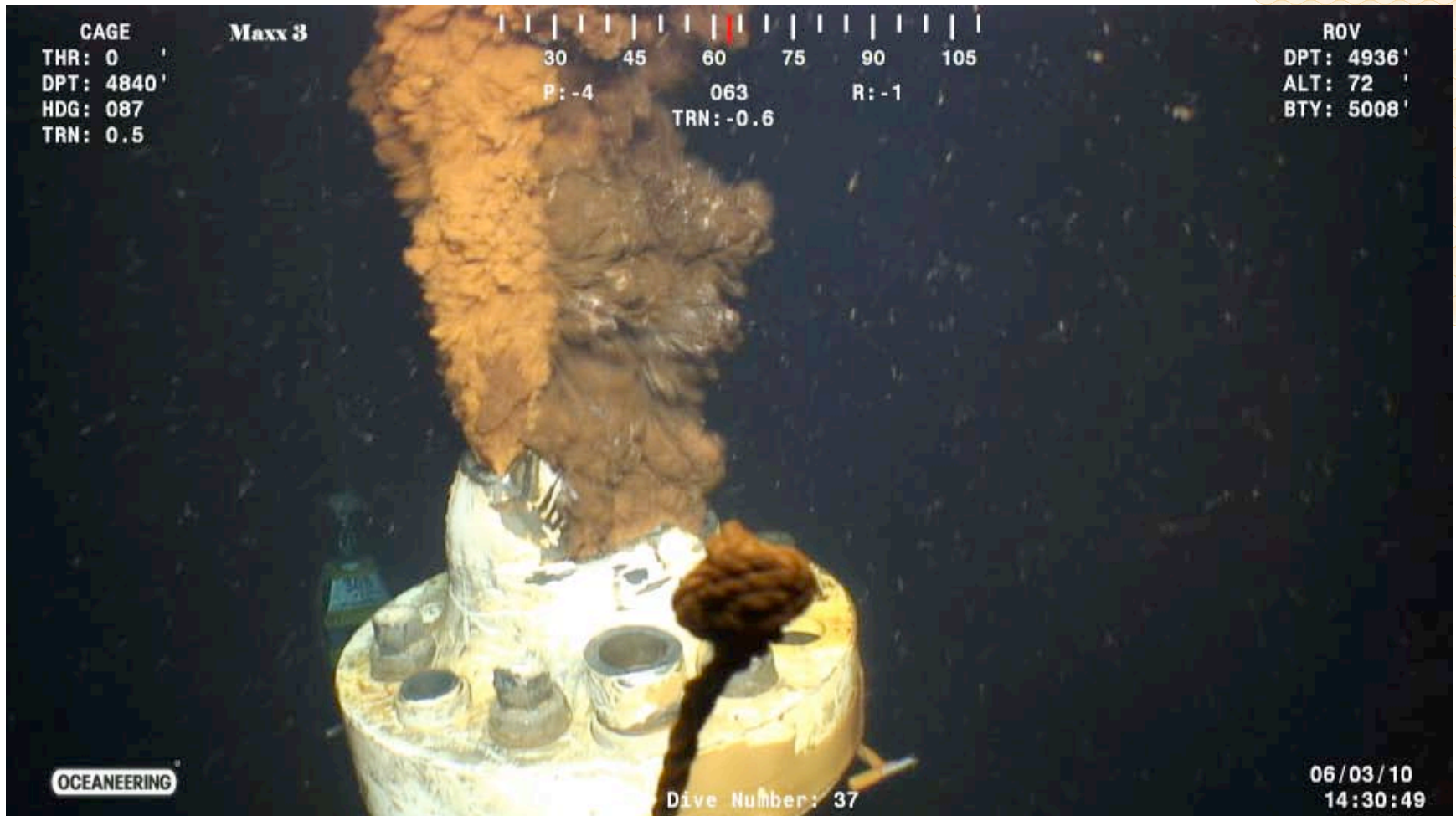


[movie](#)

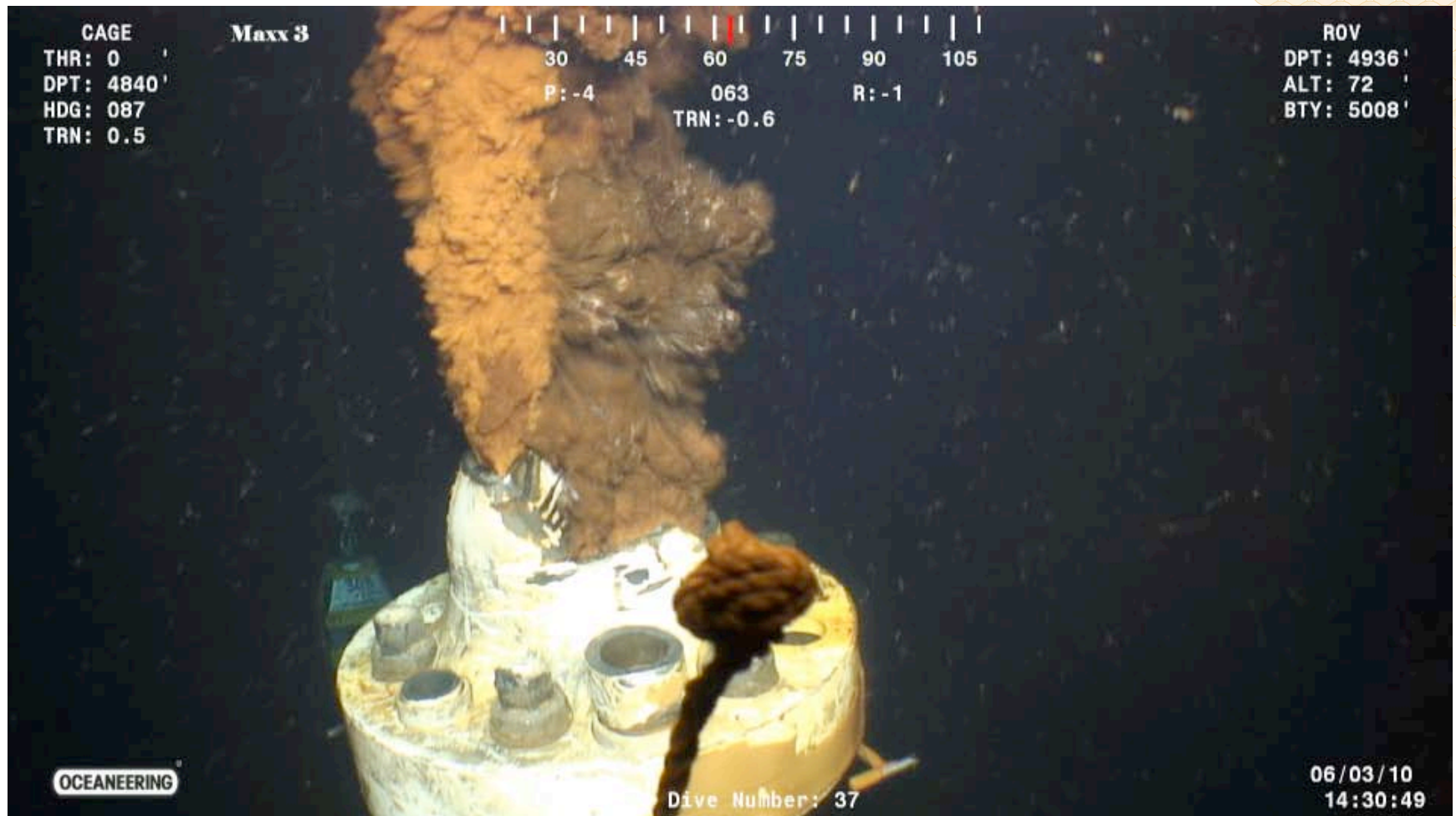
Question & Answer 1



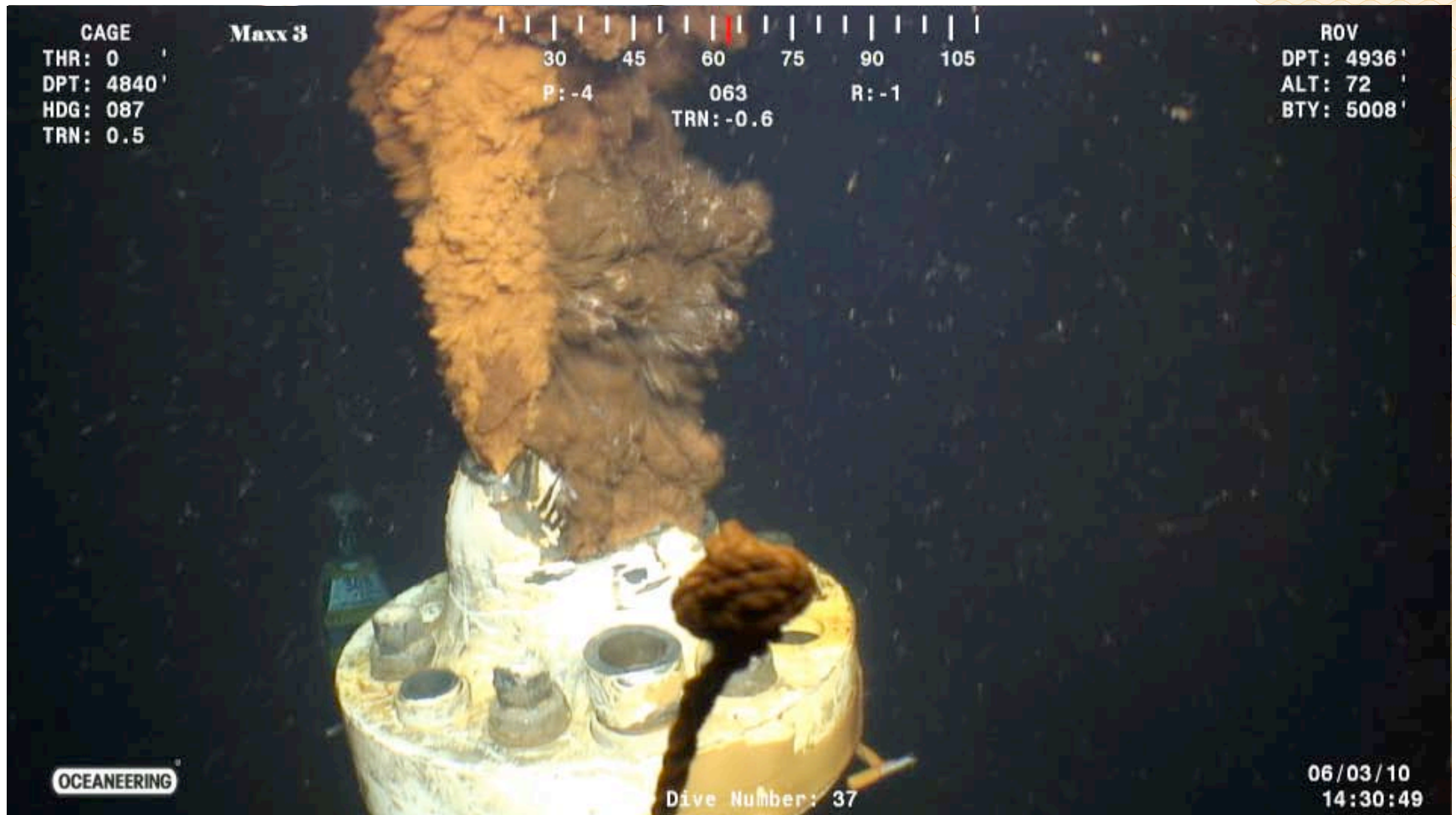
Question & Answer 2



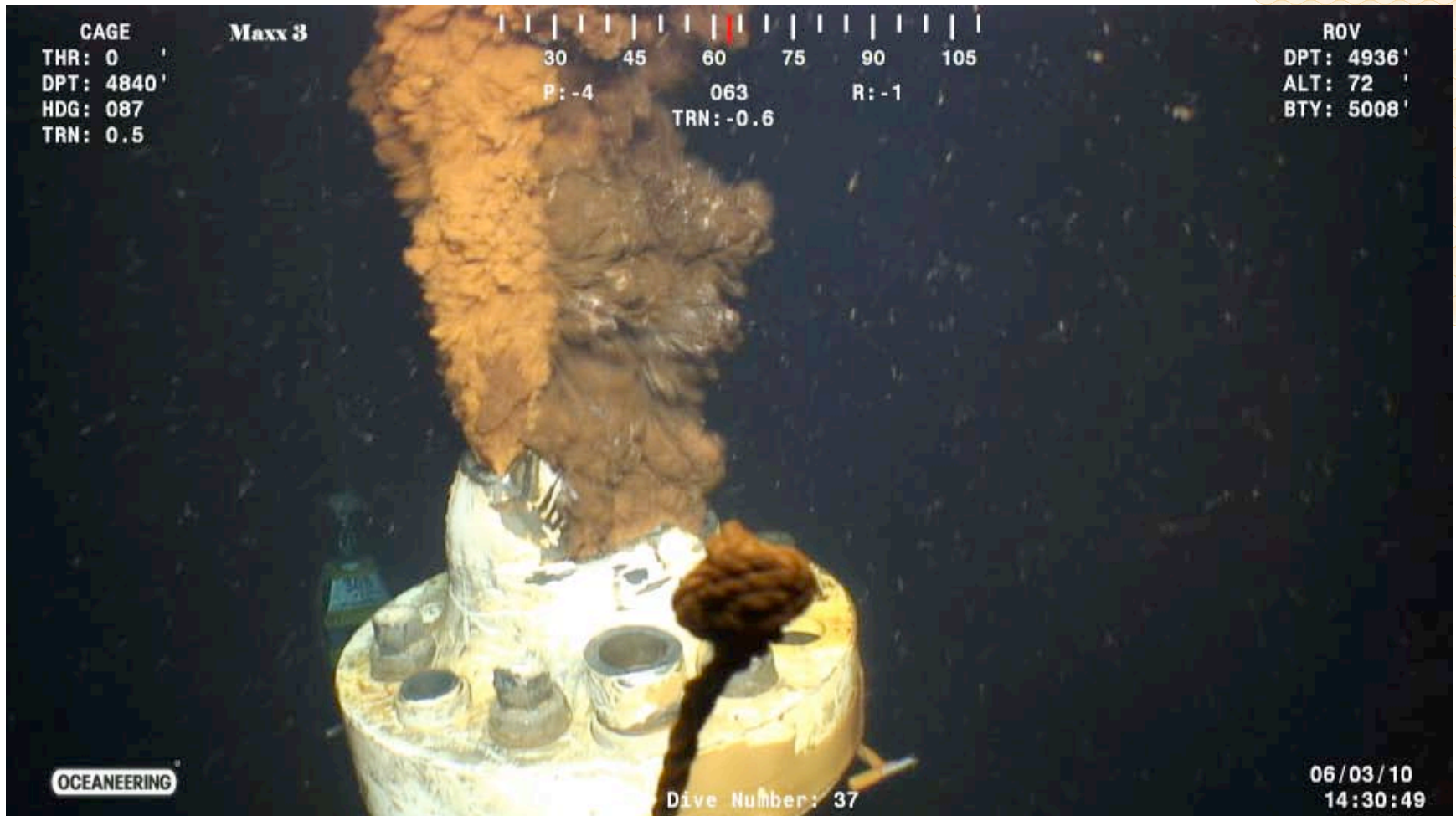
Question & Answer 3



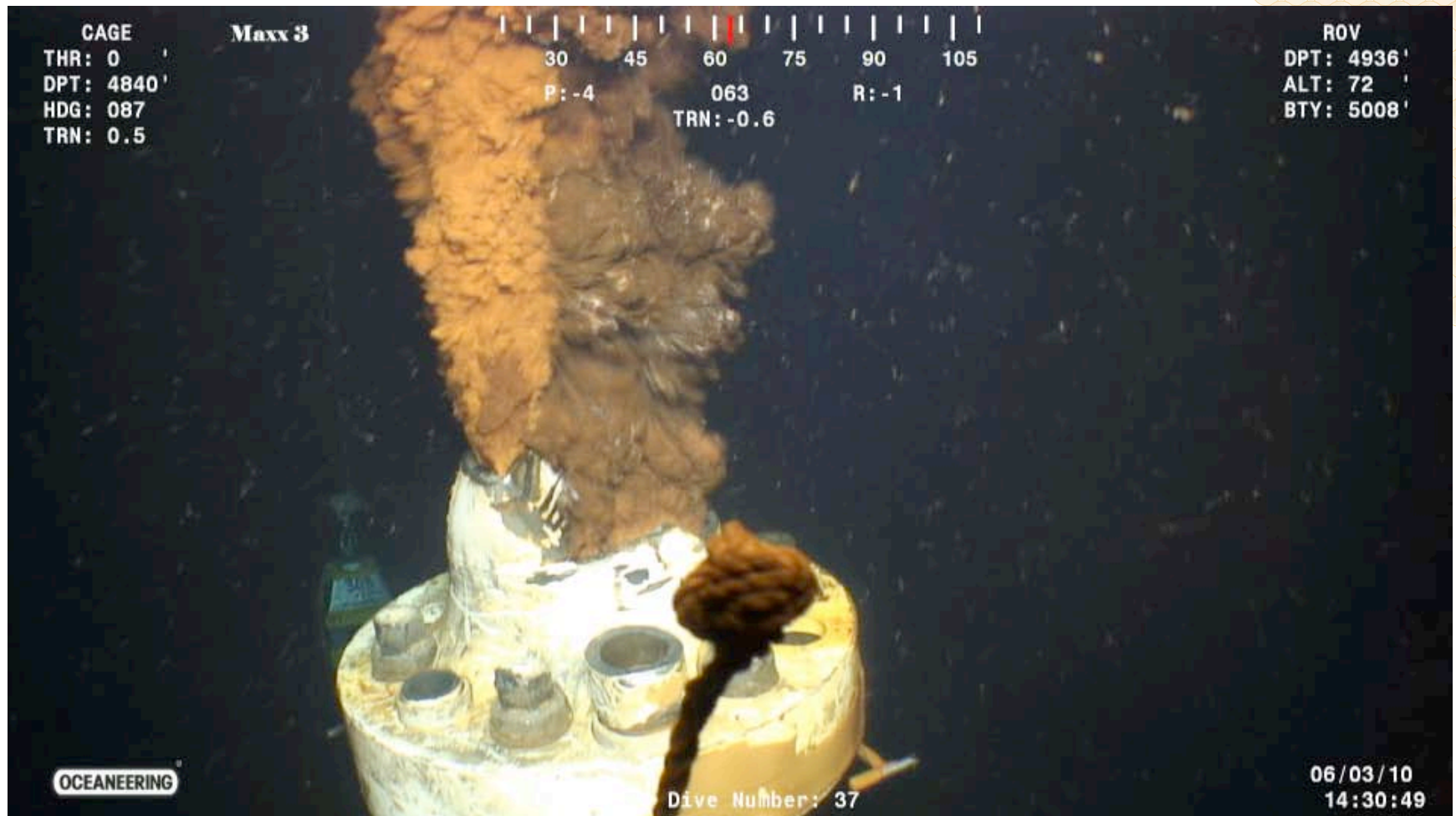
Question & Answer 4



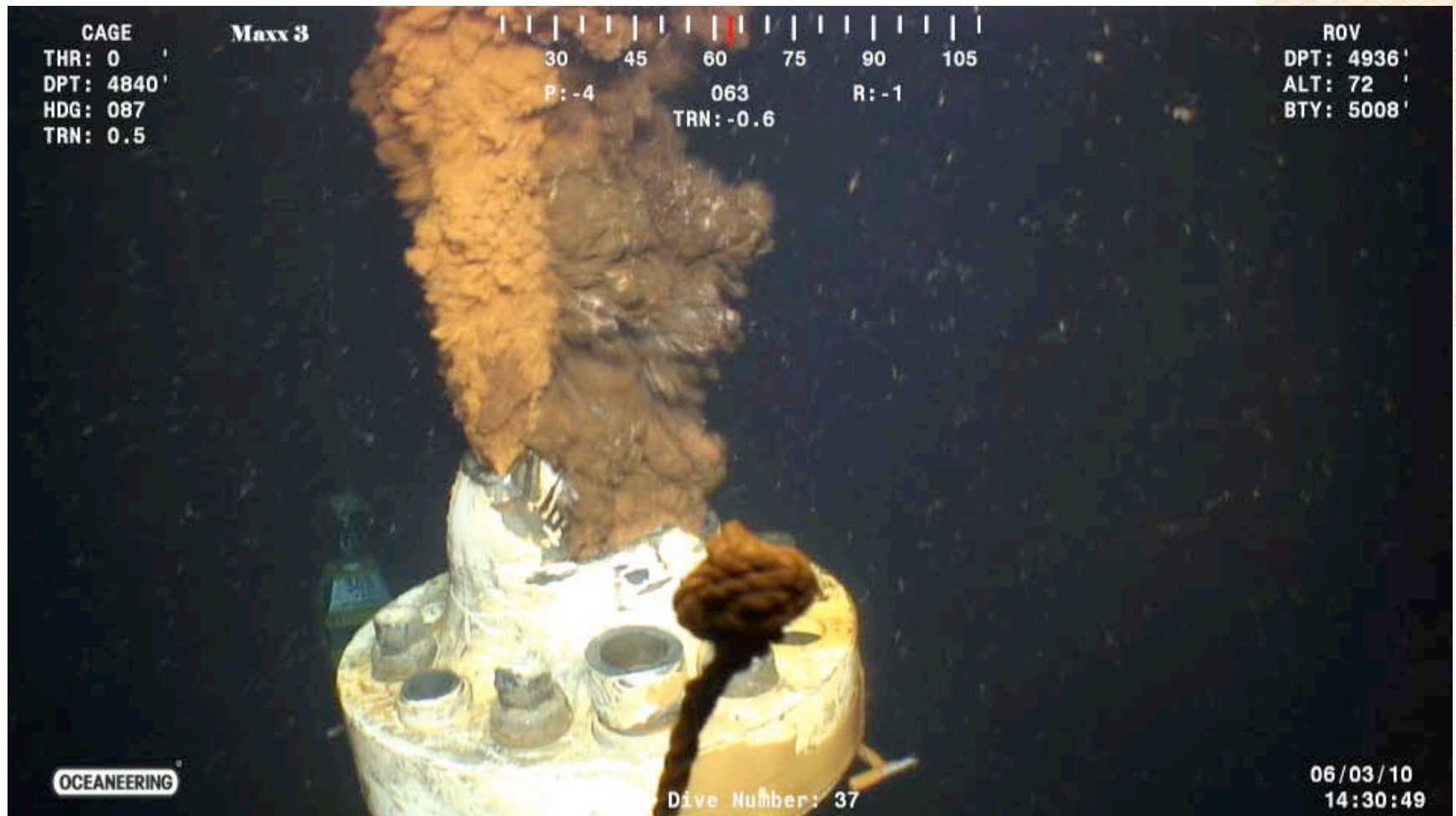
Question & Answer 5



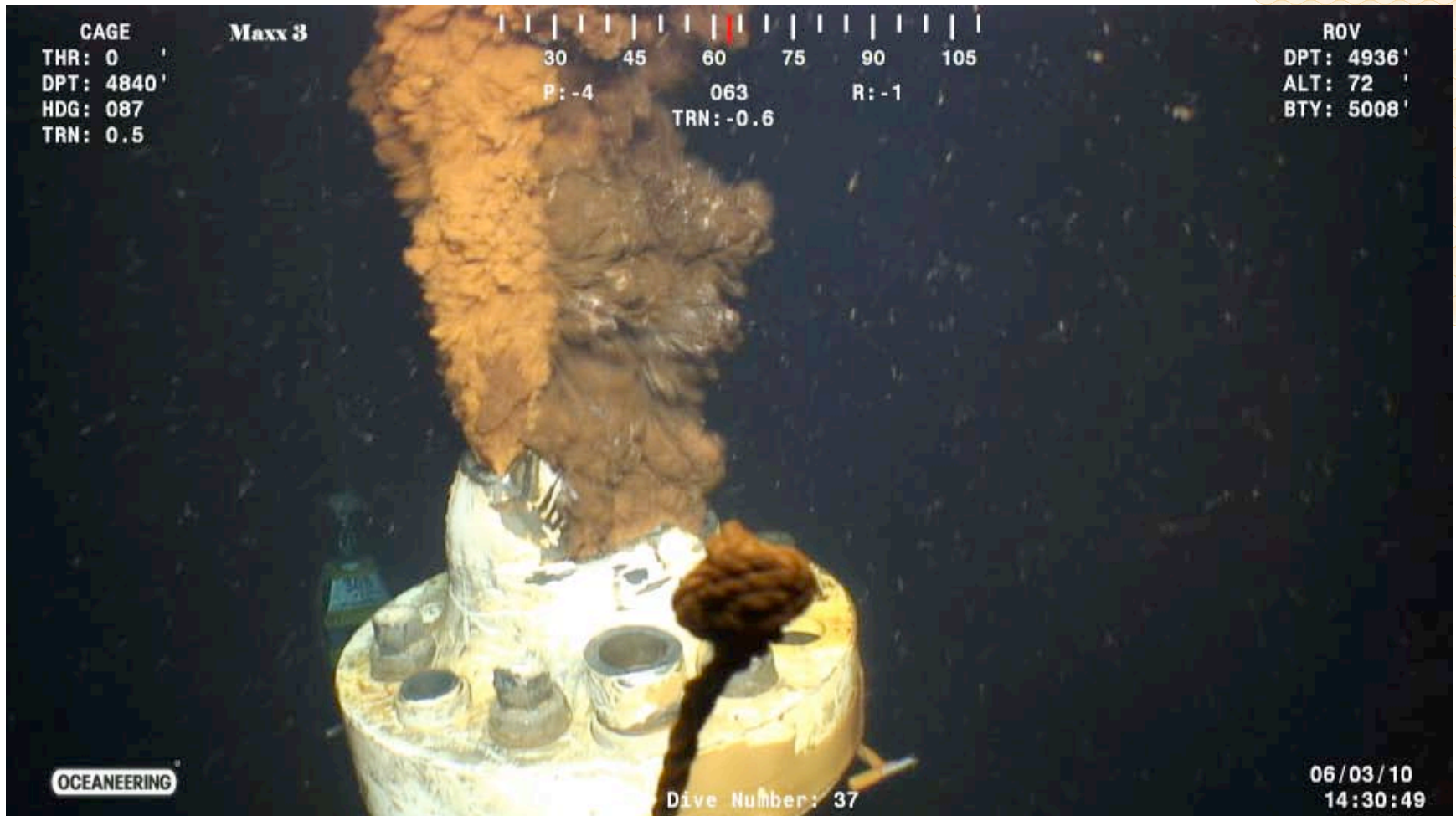
Question & Answer 6



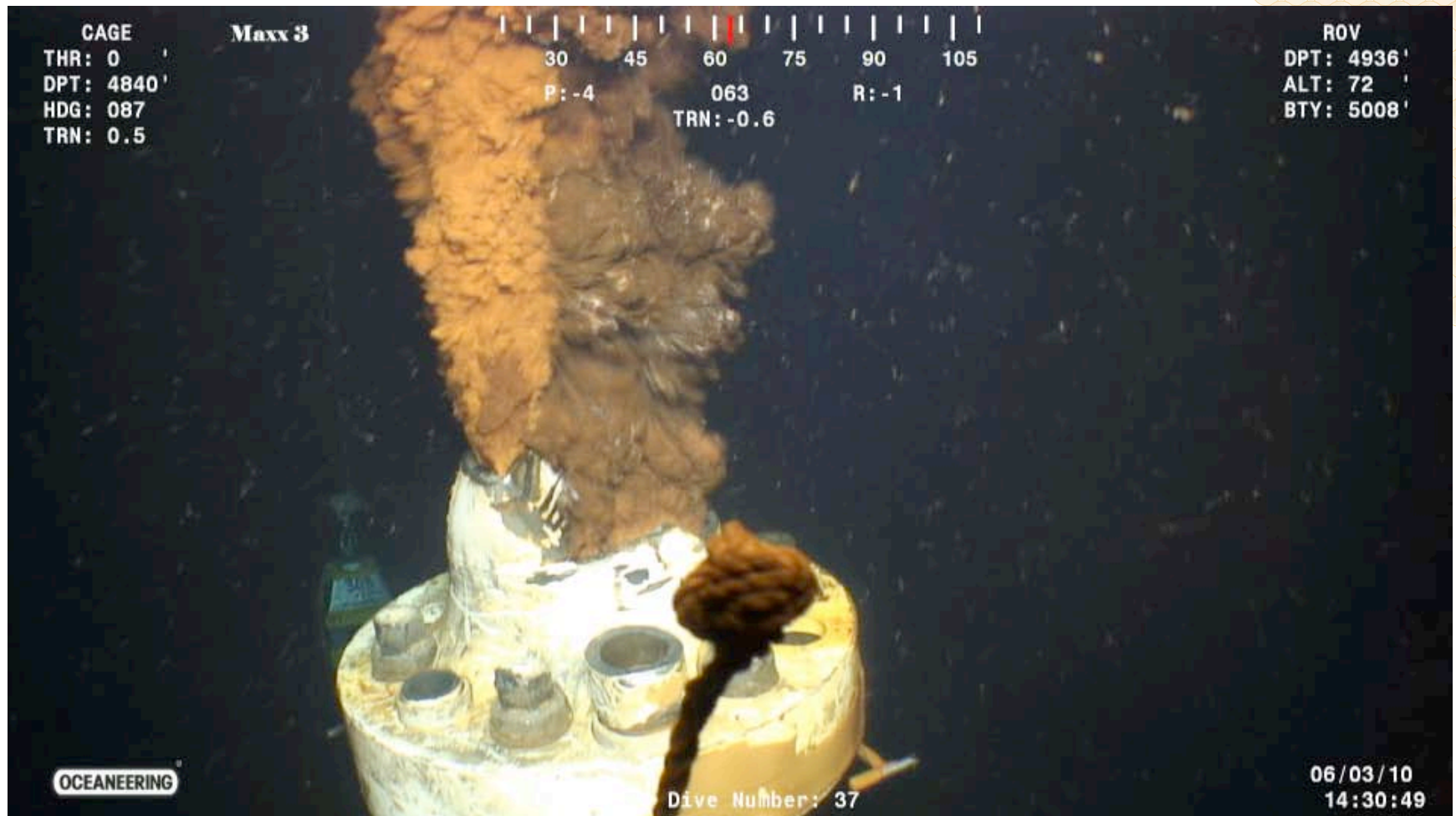
Question & Answer 7



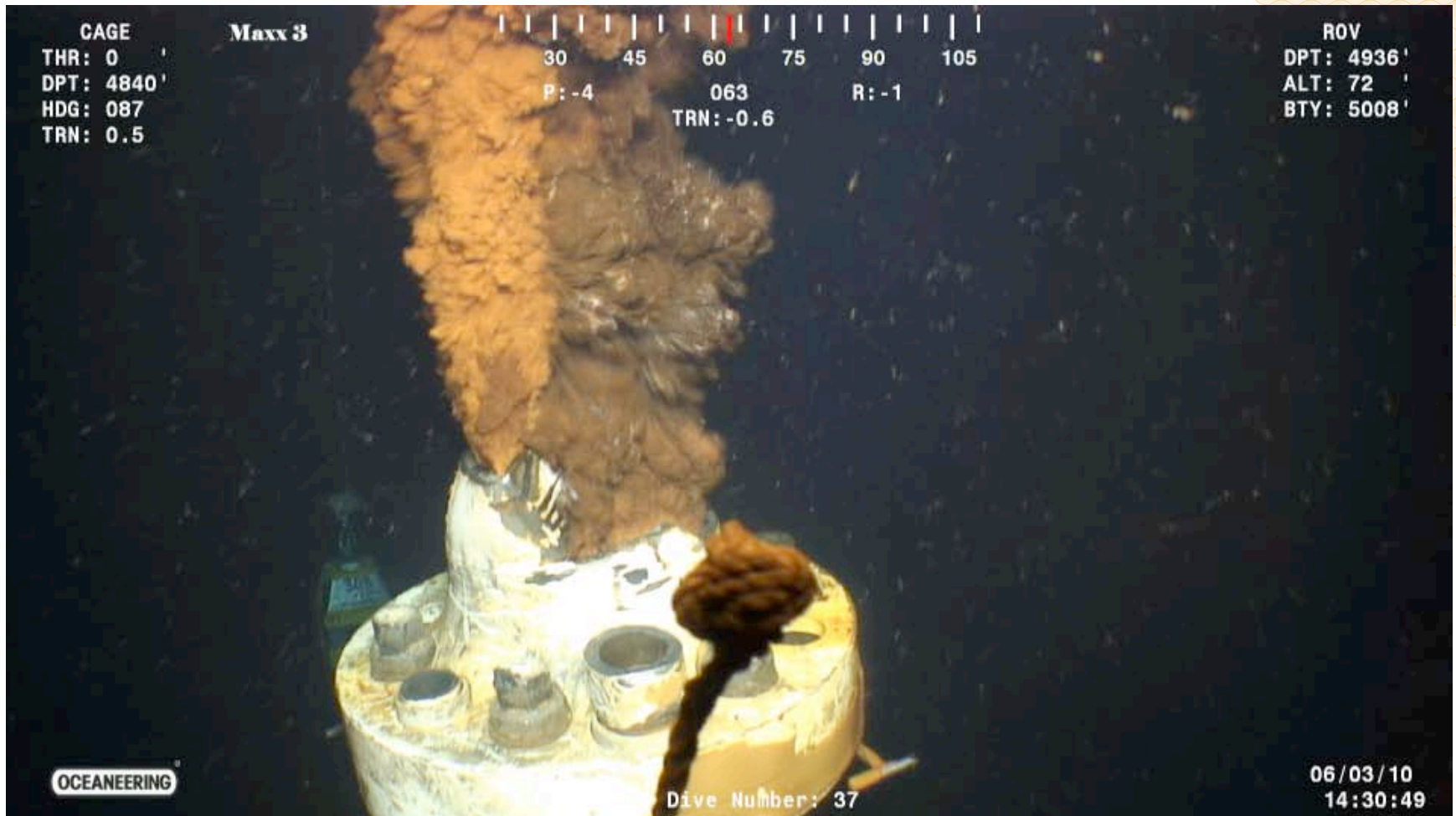
Question & Answer 8



Question & Answer 9



Question & Answer 10



Question & Answer 11

