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Experiences in Supporting Deepwater Horizon Accident Recovery Efforts

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Acknowledgment

Presentation assembled using images and results from BP reports and presentations and from the work of the NNSA-DOE Flow Team.

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NNSA National Nuclear Security Administration

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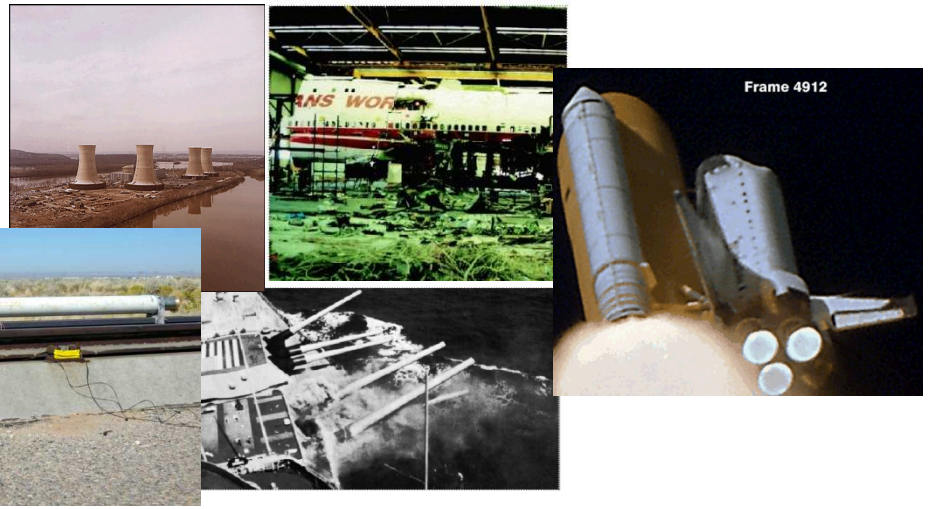
Before we start … some perspectives

I've been associated investigations and studies following several tragic events … but none like the Deepwater Horizon accident.

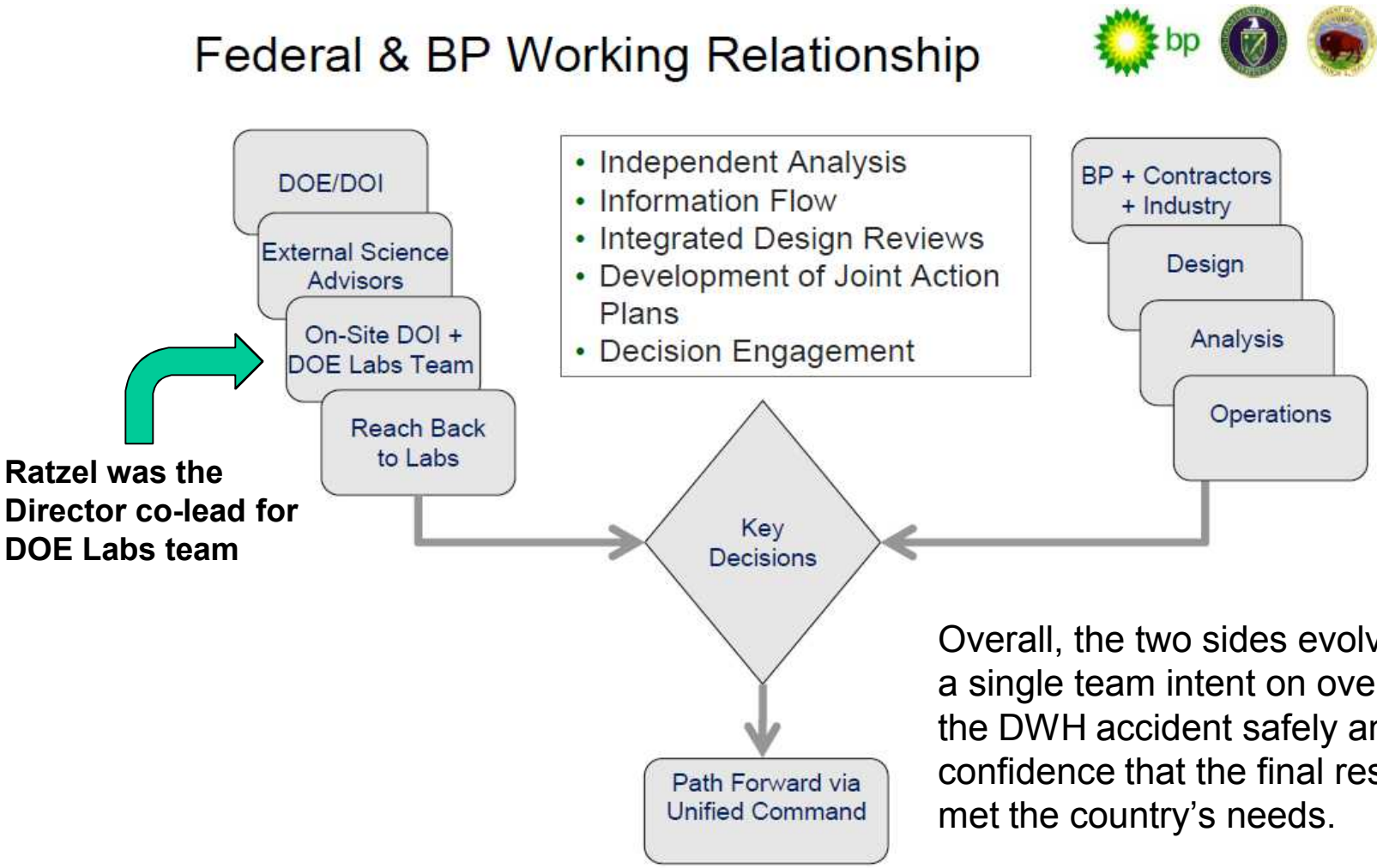


This accident brought out the strengths and resolve of all who were engaged … never a sense that there was time to rest or walk away!

Kudos to the BP team, to the DOE-NNSA and USGS-DOI scientific and engineering teams, and especially to Tom Hunter, who provided unprecedented technical and programmatic leadership that benefitted BP senior leadership, DOE Secretary Chu, DOI Secretary Salazar, and the National Incident Commander, retired USCG Admiral Thad Allen.

Perspectives (continued)

So how did the government-industry model work?



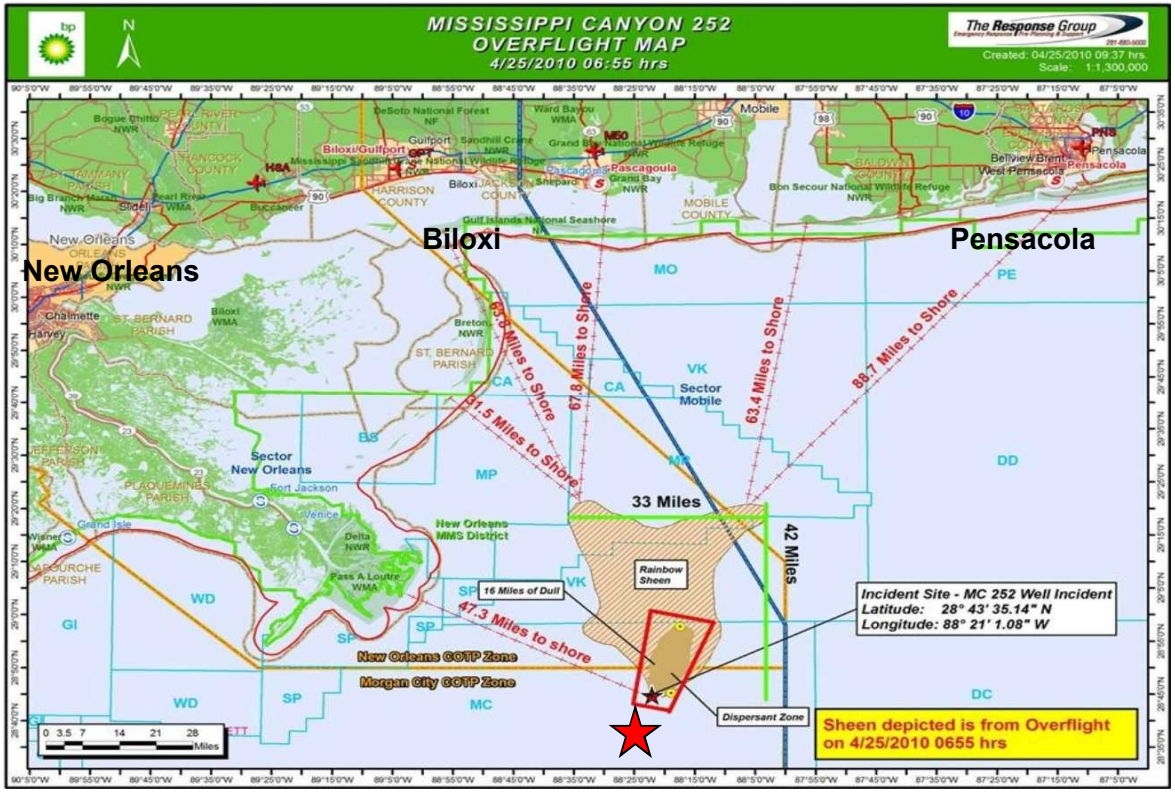
Ratzel was the Director co-lead for DOE Labs team

Overall, the two sides evolved into a single team intent on overcoming the DWH accident safely and with confidence that the final resolution met the country's needs.

Setting the Stage: Macondo Well MC-252 was drilled using the Deepwater Horizon Vessel.

Deepwater Horizon (DWH) Vessel

- Registered in the Marshall Islands, owned by Transocean ($560M)
- 396 feet by 256 feet; 52,587 tons displacement; 320 feet high



Deepwater Horizon Drilling Ship prior to the accident

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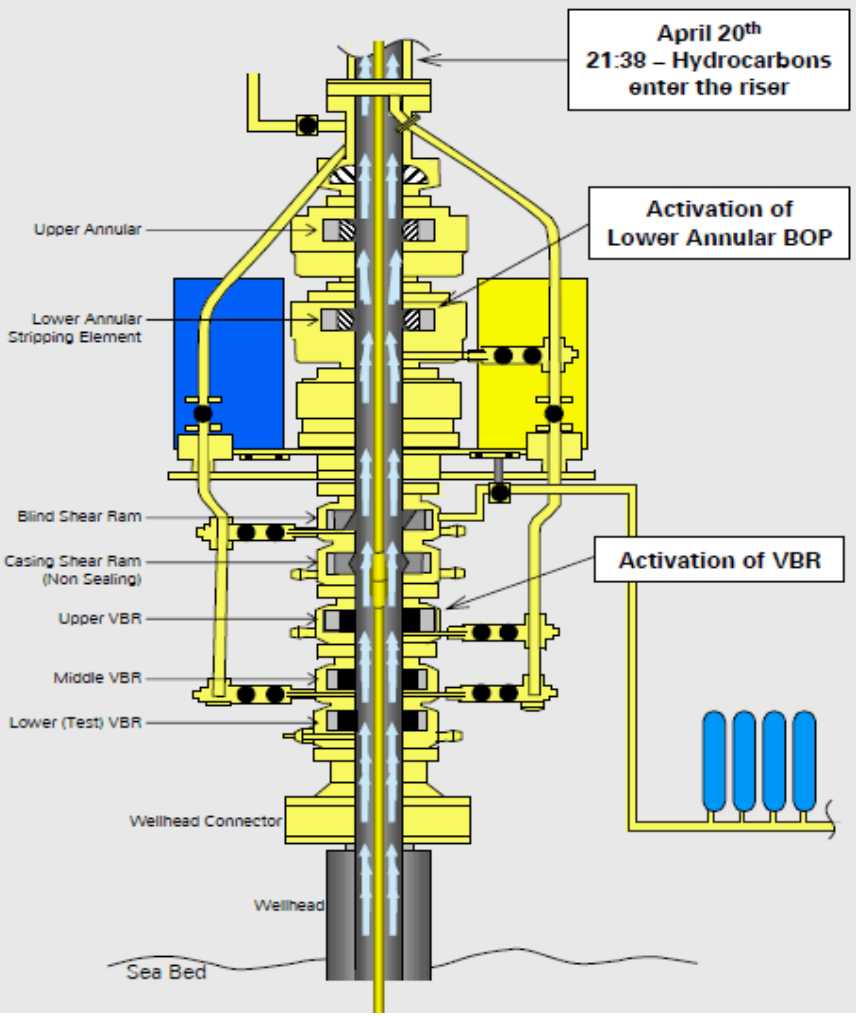
On April 20, 2010, following completion of Macondo Well MC252 and prior to final cementing and well shut-off, the accident occurred.

Eleven individuals (drillers and DWH personnel) were killed.

The DWH sank April 22. The drill string broke off and ~5,000 feet of pipe connected to the Blow-out Preventer settled on the Gulf floor.

When the DWH crew realized something was "wrong," they attempted to minimize the extent of damage by trying to shut off flow through the Blow-Out Preventer on the well head.



BOP is designed to seal the wellbore and shear casing or drill pipe if necessary.

April 20th

- 21:41 annular BOP closed but appears not to have sealed the annulus
- 21:47 a VBR likely closed and sealed the annulus

Unfortunately, closure of the RAMs did not seal the well.

Additional attempts were made after the accident to activate the closure systems, but did not succeed in stopping the oil and gas flow.

Early on it was recognized that oil and gas were being released from the riser drill string. The quantity of flow was not known.

Riser Kink Outflow Close Up

Riser Kink Far Field

Riser Kink Outflow

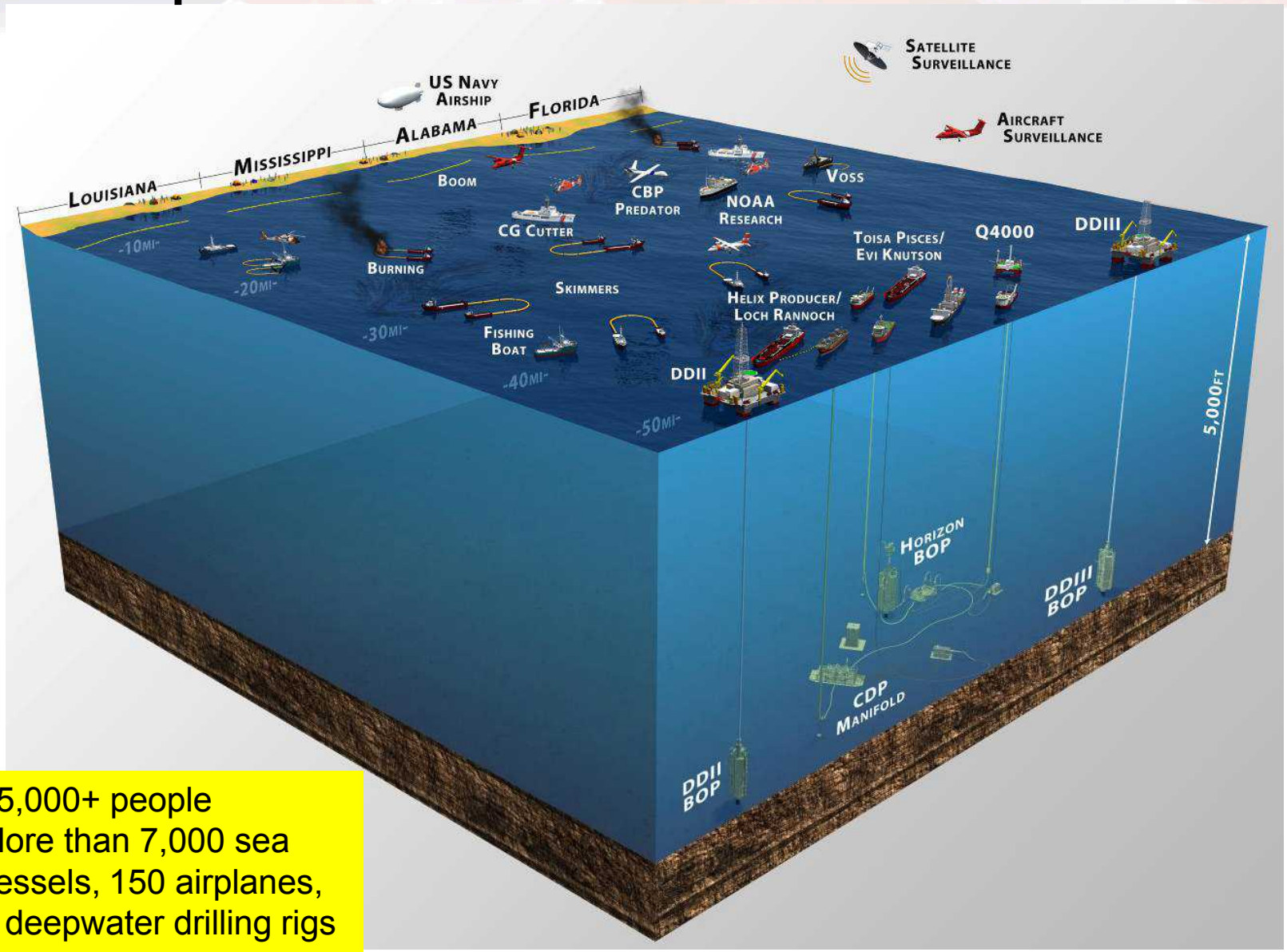
Video images from ROVs stationed on the Gulf floor showed that the drill string had been damaged following separation from DWH.

Afterward, there was oil, and the race began to shut down the flow.

The spill reached landfall from the eastern-most Texas coast (minimally) to Florida. The bulk of flow reached Louisiana.

Fortunately, no significant tropical disturbances or hurricanes were in the Gulf in 2010. Flow analyses predicted oil spread that would have "coated" the full Texas coastline.

Deepwater Horizon Accident - Extent of Efforts



- 45,000+ people
- More than 7,000 sea vessels, 150 airplanes, 6 deepwater drilling rigs

And what it looked like above the Macondo well head in the Gulf of Mexico.

Activities during the early days: Events leading up to well shut-in.

- BP engaged in a number of efforts from the end of April through shut-in on July 15.
  - Started intercept wells.
  - Attempted to stop flow: "Top-Kill"
  - Organized multiple collection systems.
  - Performed a number of "what-if" studies to evaluate well integrity.

Timeline of Events leading to well shut-in 87 days after the DWH accident.

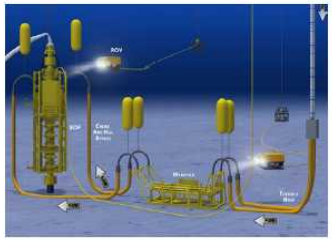
Date	Time, if available	Events—Flow Conditions	Collection
20-Apr		**Explosion and fire; oil continues to flow to damaged platform at ocean surface.**	**None**
22-Apr		**Rig sinks; oil and gas flow into ocean from sunken riser.**	**None**
8-May		Cofferdam lowered on broken riser; fails because of icing.	Attempted
26-May		**Top Kill begins.**	**None**
29-May		**Top Kill ends – Unsuccessful.**	**None**
3-Jun		Second shear cut.	None
3-Jun		Top Hat # 4 installed (Enterprise recovering).	Enterprise online
16-Jun		Top Hat # 4 operational (Q4000 online and recovering from BOP manifold line).	Enterprise and Q4000 online
12-Jul		**3-Ram Capping Stack landed/secured.**	**Q4000 online**
13-Jul	**~4:00 PM**	**Started Well-Integrity Test; shut-in operations initiated.**	**None**
15-Jul	**2:30 PM**	**Well-Integrity test shut-in completed.**	**No flow; shut-in**

Early attempts to minimize and stop the flow were unsuccessful.

The Top-Kill exercise was performed May 26 to 28 to stop oil flow and kill the well by forcing mud and "junk" down-hole.

- Top Kill Statistics:
  - 3 separate attempts over 3 days.
  - Pumped total 30,000 barrels of heavy mud at rates up to 80 bpm, 11,000 psi surface pressure, 6,000 psi wellhead.
  - Fired 17 different bridging material shots (varying sized balls, cubes and misc objects).
  - 29 vessels in the area, including 10 ROVs.

- Top Kill #1 May 26th
  - Pumped 13,100 bbls, 16.4 ppg, 53 bpm
- Top Kill #2 May 27th
  - Pumped 6,800 bbls, 16.4 ppg, 25 bpm with 15 shots of bridging materials
- Top Kill #3 May 28th
  - Pumped 9,800 bbls, 16.4 ppg, >70 bpm, with 2 shots of bridging materials



Cofferdam structure placed on broken riser on May 8; failed because of icing.

Following Top-Kill, BP Focused on Collection and Containment Activities

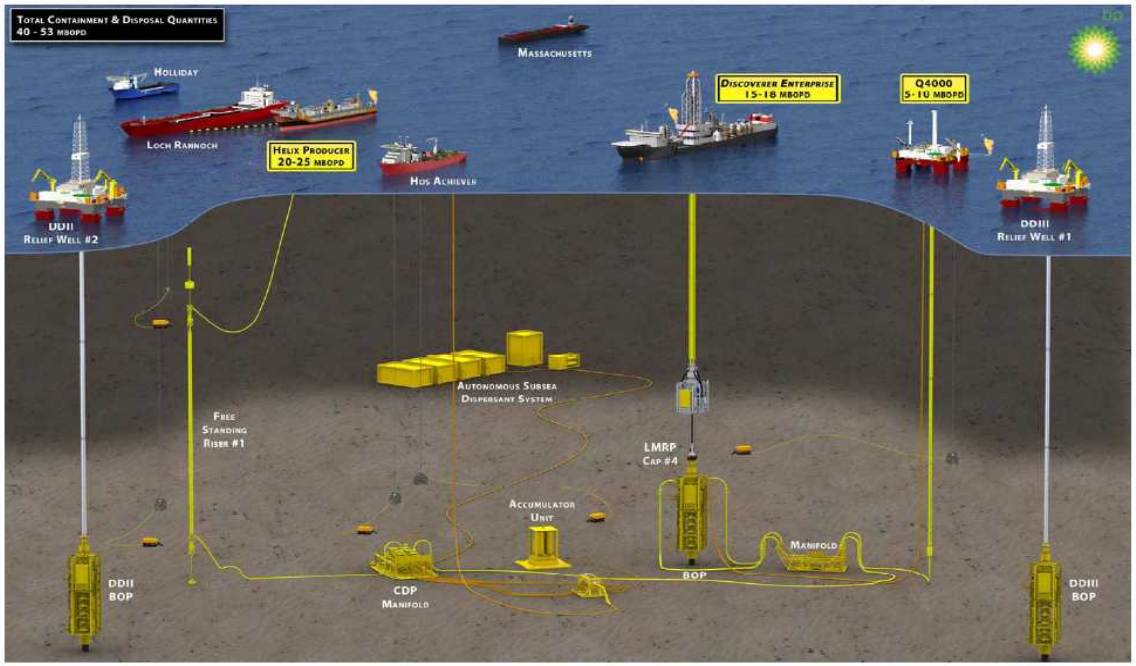
Top-Hat System

Flow images from the top of the BOP after removal of the kinked riser section (top) and flowing out from Top Hat skirt (bottom)

Capping Stack System

BP aggressively "attacked" to minimize the oil release to Gulf; just prior to capping the well-head, three oil recovery systems were in operation.

Containment: Early July
Capacity 40 – 53 mbd



Principal recovery ships

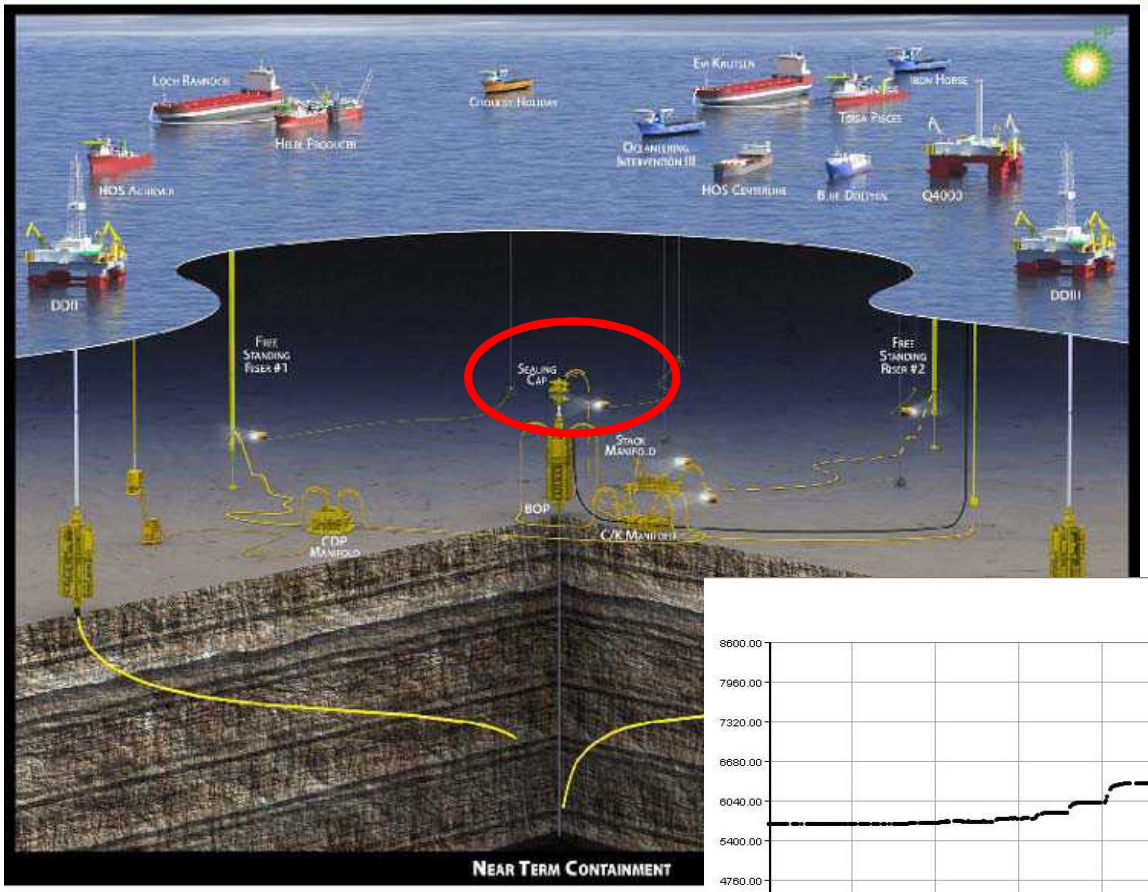
- **Discoverer Enterprise** (~15K bbl/day); collected through the Top Hat collection system.
- **Q4000** (<10K bbl/day); collection through the BOP/Top-Kill manifold.
- **Helix Producer** (capable of ~20K bbl/day) Was coming online in mid-July just prior to shut-in.

Captured oil was collected and transported away; natural gas was flared. Temperatures on-board the deck of the Q4000 surpassed 100°F during summer despite efforts to "wet down" the deck.

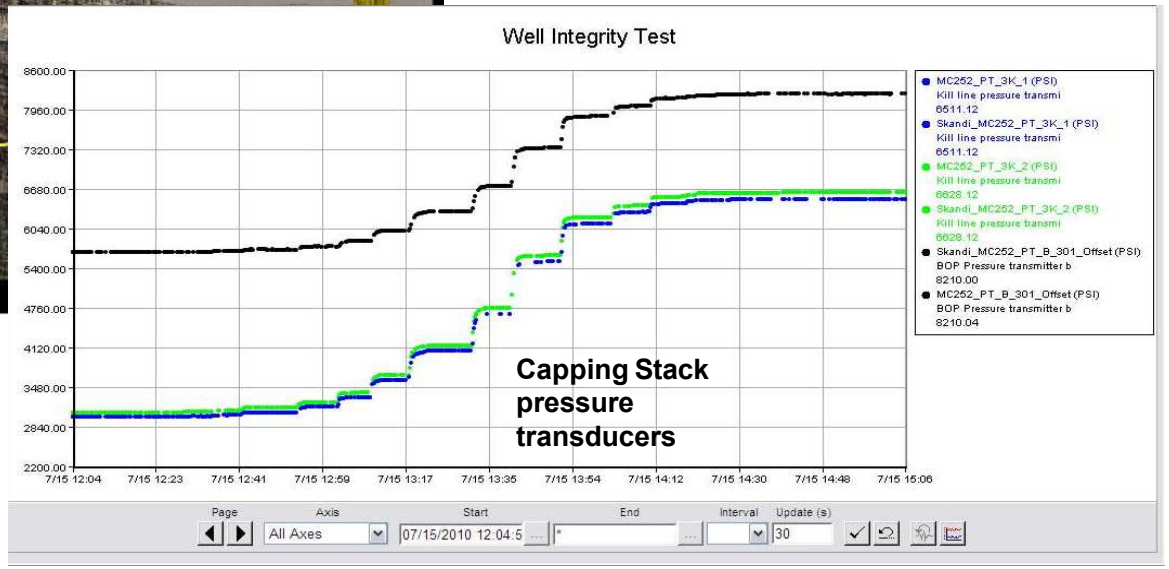
40+ Vessels

1500+ People

And then on July 15, 2010, the well was capped!



Well was shut down using controlled closure of a choke valve installed on the Capping Stack.



No oil flow to the Gulf after July 15, 2010!

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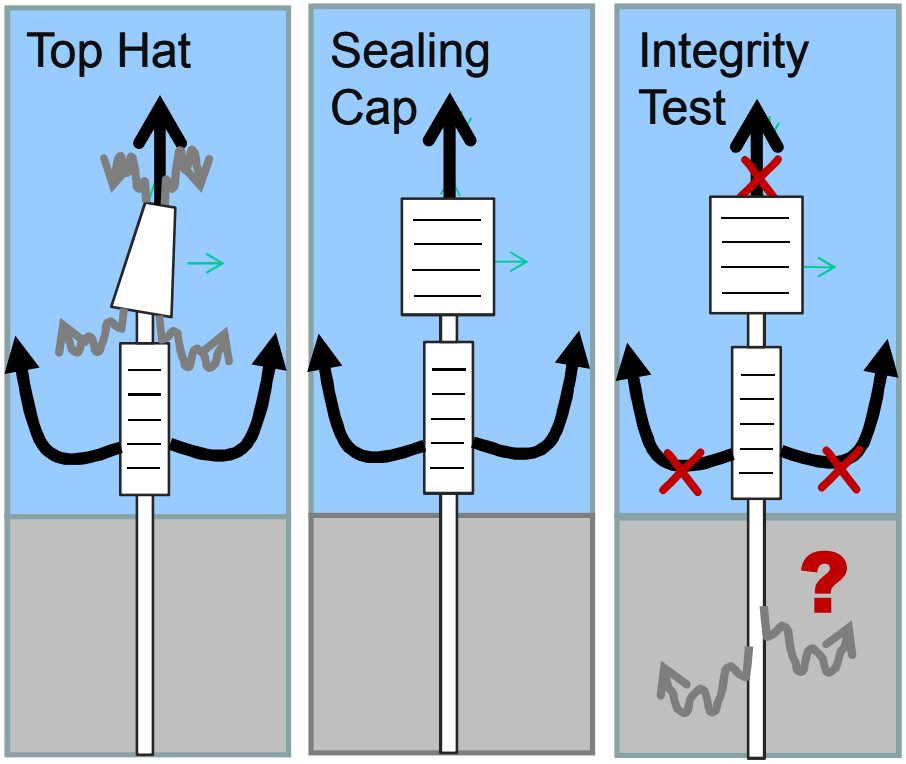
Following shut-in, BP and government teams systematically worked to "plug" and abandon the well.

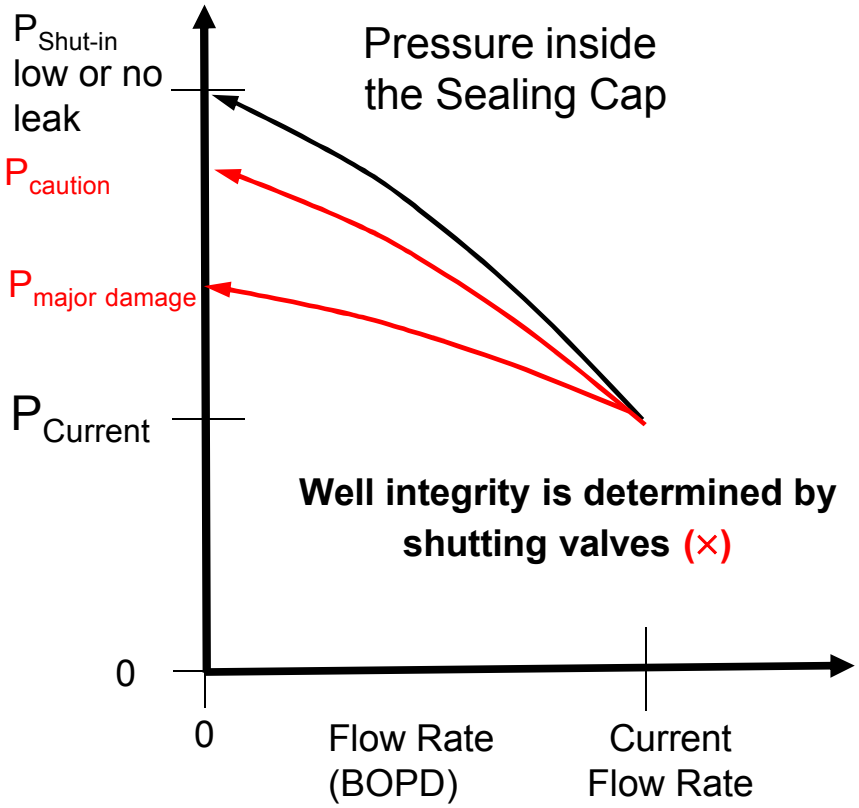
Key activities included the following:

- Well-Integrity Testing: July 15 – Early August
- Static Diagnostics Test (Top-Kill 2): August 3-7
- Ambient Tests (Confirm no flow): August 9-17
- BOP Replacement: September 3-4
- Relief Well Intercept/Cement: September 16-18
- Government announcement that the well was "killed" ~ September 18
- Plug and Abandonment Activities - October

Well-Integrity Concerns: What if the well was damaged?

Prior to well shut-in, concerns were raised about whether capping could lead to catastrophic consequences; if the accident had damaged the well, would there be flow into the strata?



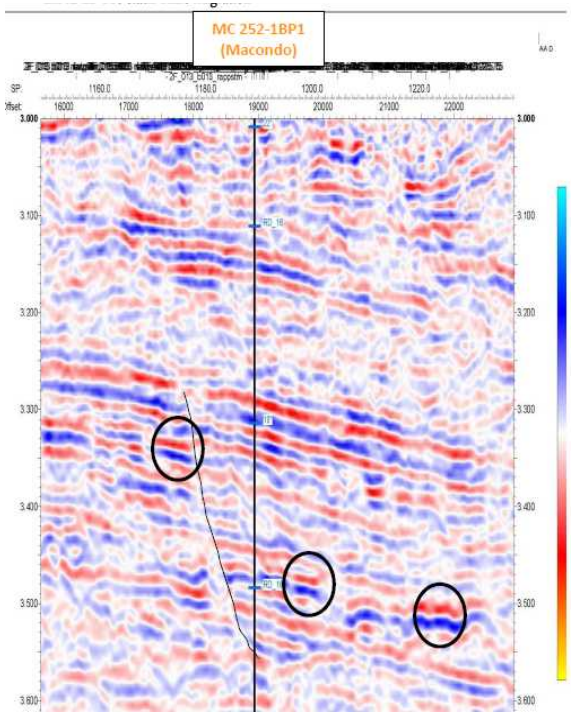


Well-integrity concerns led government leadership to require extensive sonar, visual, and seismic monitoring following shut-in.

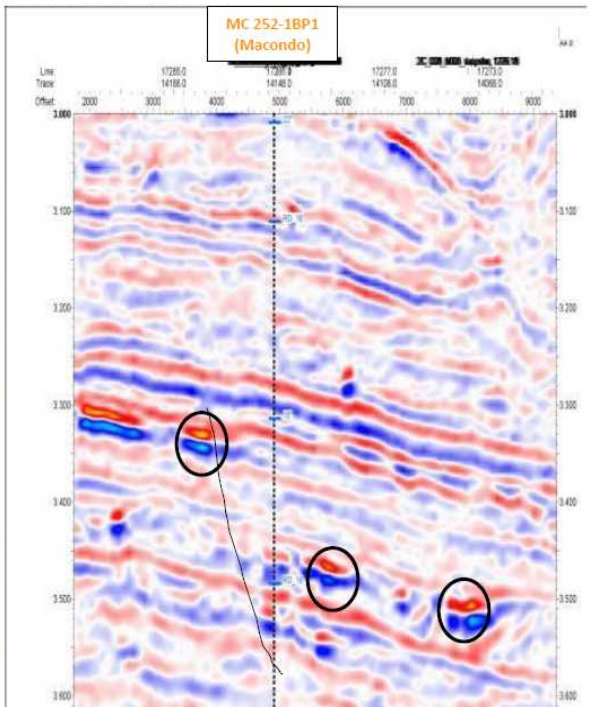
Well-integrity monitoring was a major focus for BP and government leadership immediately following well shut-in.

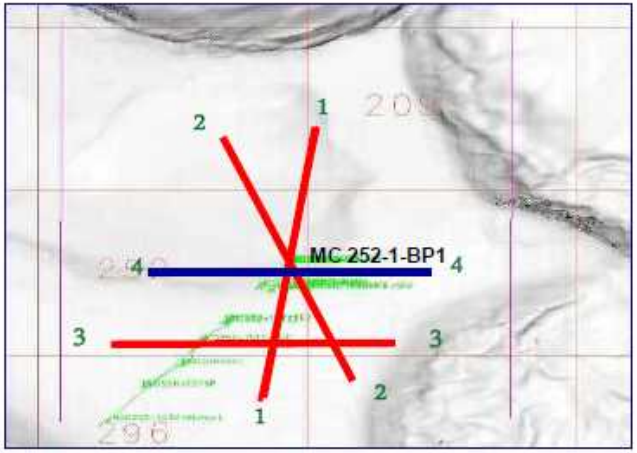
3-D seismic data were provided daily using surface ships that traversed the seas above and around the Macondo Well.

Seismic data from late July



Seismic data pre-accident





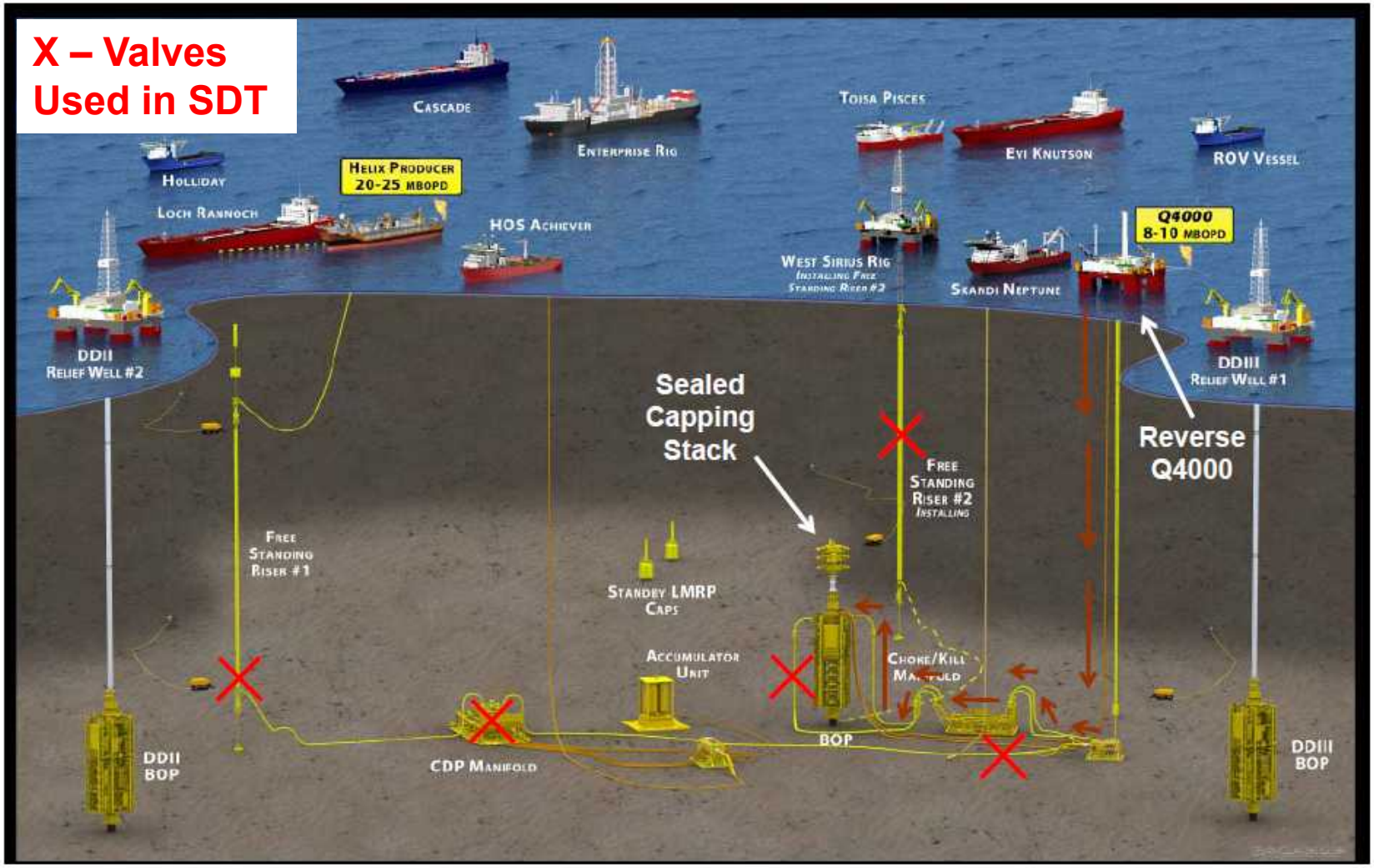
Seismic data collected from surface ships followed tracks that would allow assessment of well integrity.

No indication of well oil leakage after three weeks of extensive monitoring.

"Seeing the light at the end of the tunnel"

Successful completion of the "Static Diagnostic Test" in early August

culminated with cementing of the lower section of the well.



Every step along the way required extensive "What If" analyses.

(August 2010: Lift strategy for BOP and drill pipe)

Option 1:
BOP rams closed; pull LMRP, BOP, and DP.

Pull; Is the DP still attached?

No

Expected lift to occur for loads >590K#

Yes

Expected lift to occur for loads >640K#

Possible assistance separating H4 Connector from well-head; Pressurize BOP and DP to support H4 connector lift-off. **(Not recommended by Transocean or BP.)**

Increase load until BOP lift begins **(magnitude depends on H4 connector);** track load history to assess if DP connected to casing.

DP Connected

DP Not connected

Complete lift; well integrity maintained.

Hold Point: Back off on load to ~590K# and open BOP Rams

Increase load until BOP lift begins; track load history to assess whether DP attached to BOP.

BOP pulls free of DP

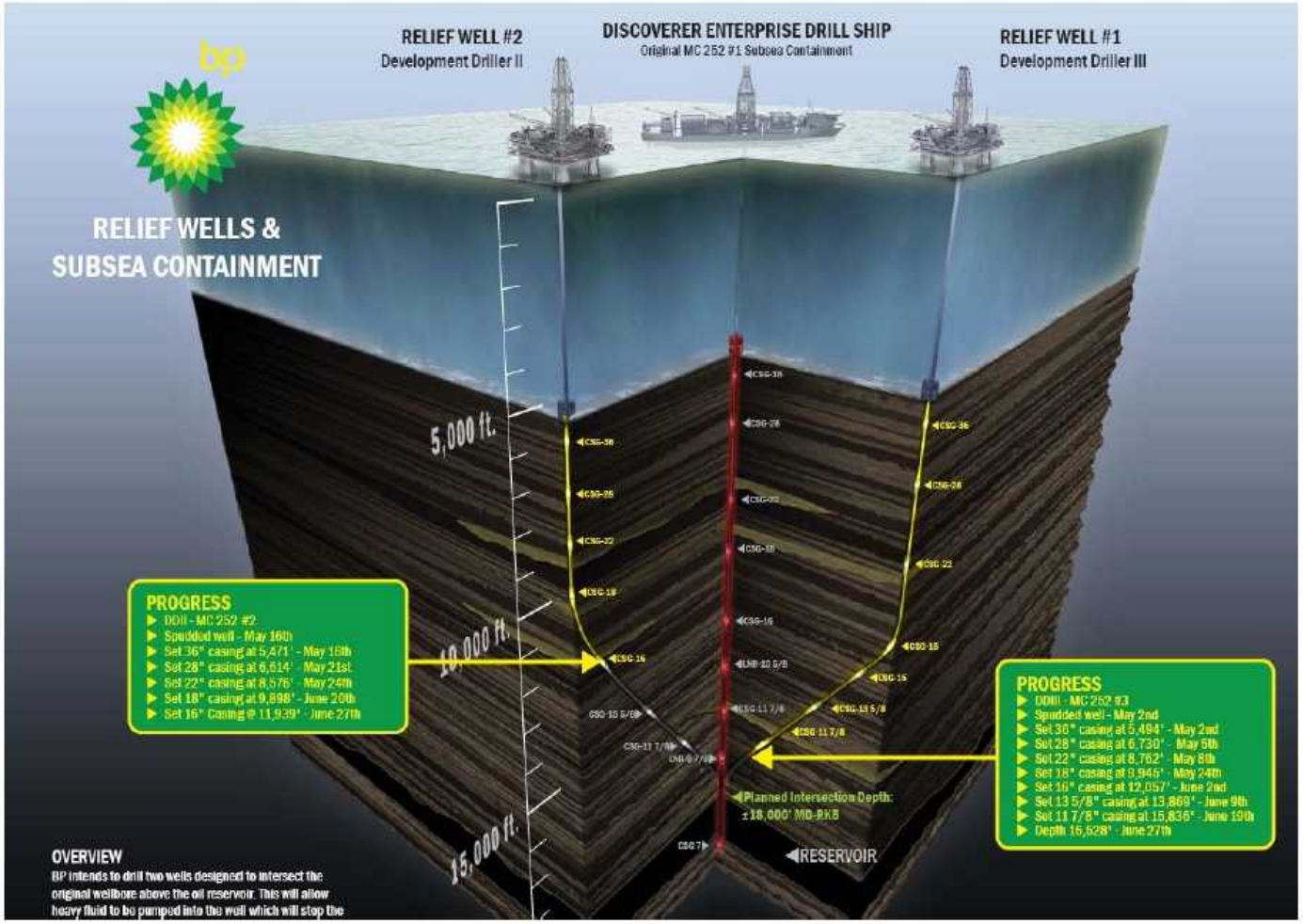
Complete lift; well integrity maintained.

DP remains part of BOP

Hold Point: Tough Decision

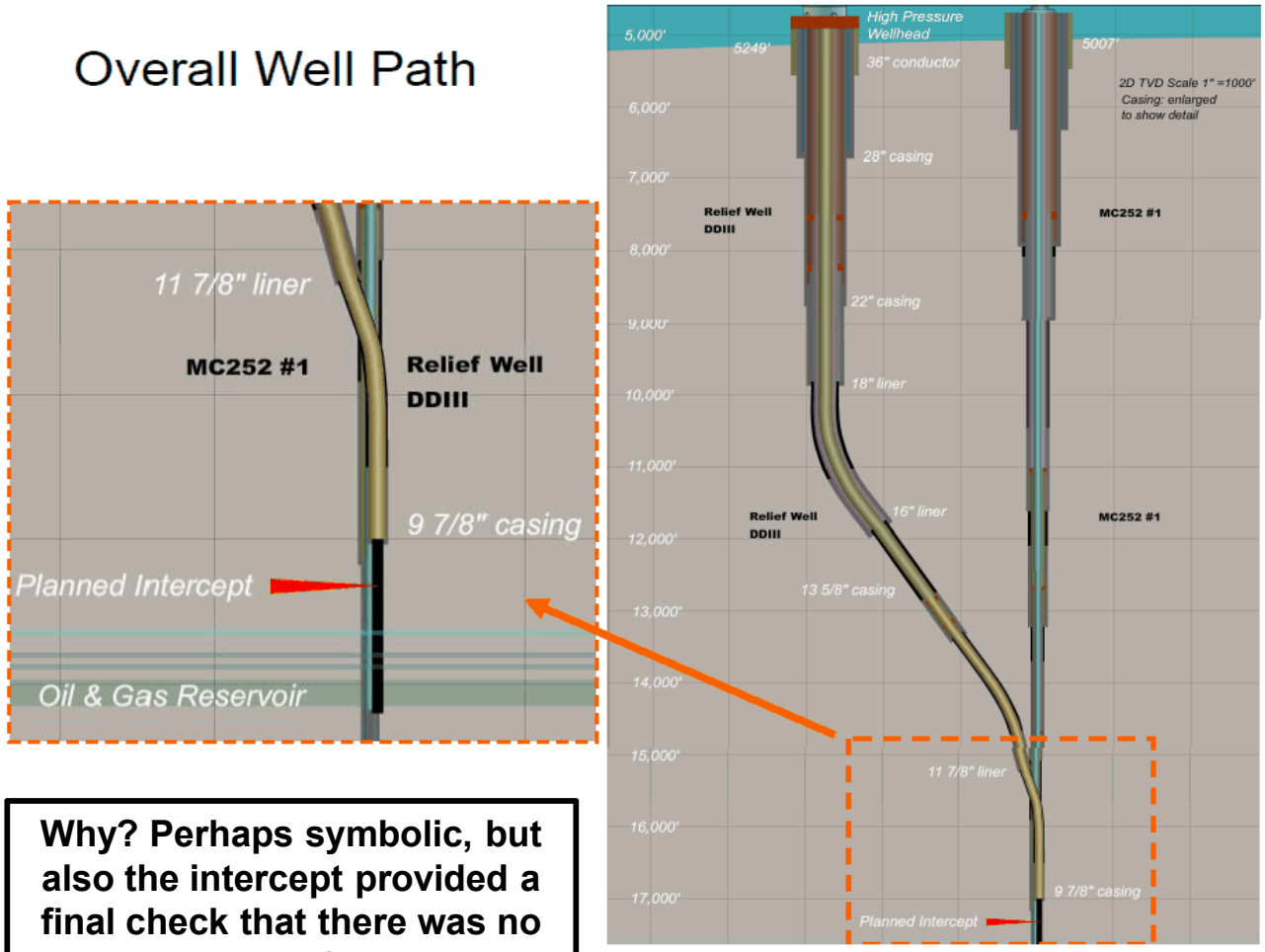
- Load until break free (risk hanger damage)
- Remove LMRP and install DD2 BOP on Horizon BOP
- Reinstall CS and proceed to DD3

BP developed a well-intercept strategy early on to provide an alternate path for "killing" the well flow.



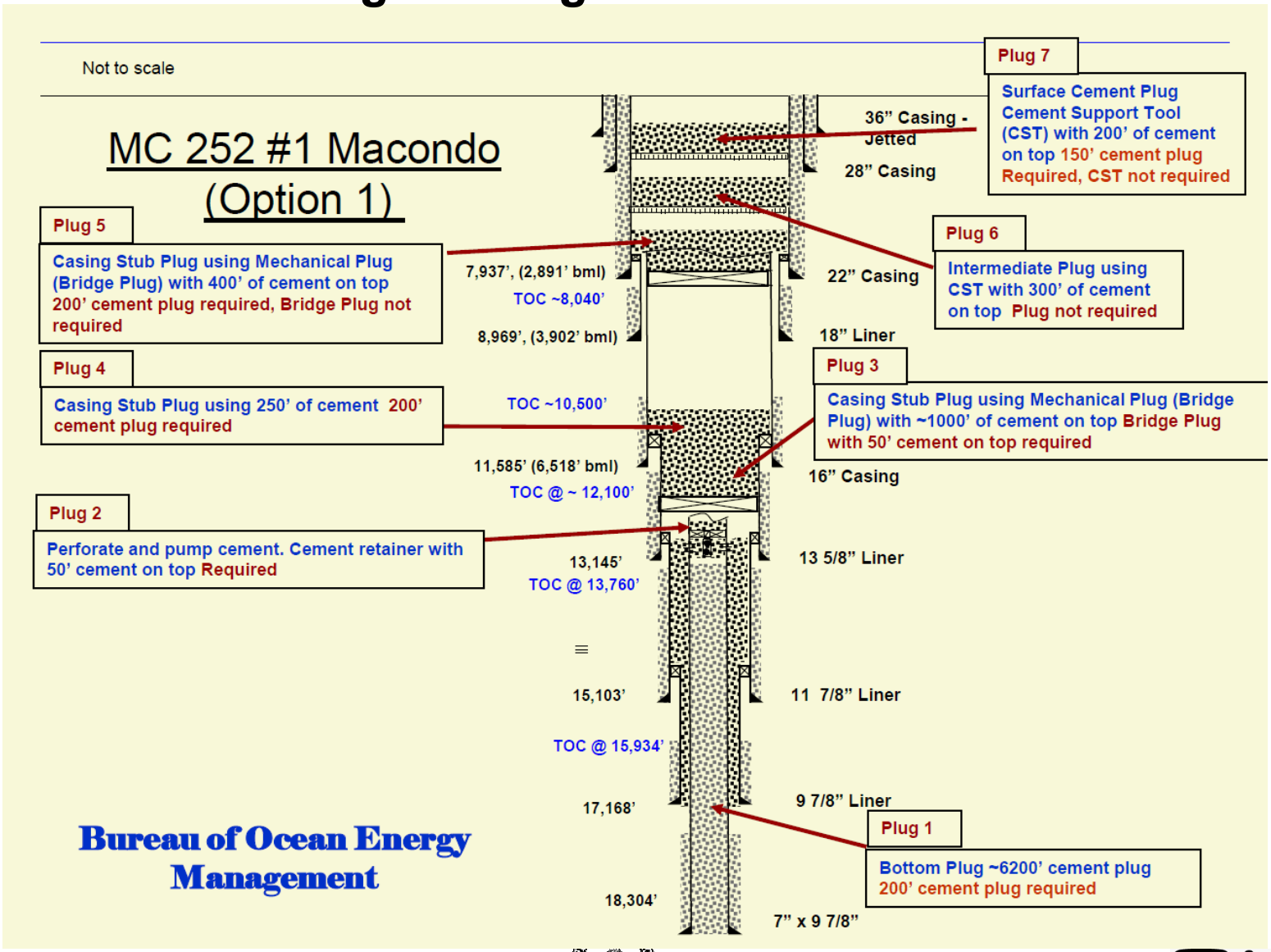
Well intercept became the backup for well-kill;
after the BOP was replaced, traditional kill processes were used.

Perhaps the Greatest Engineering Feat of All: The Well Intercept in September



Why? Perhaps symbolic, but also the intercept provided a final check that there was no annular flow!

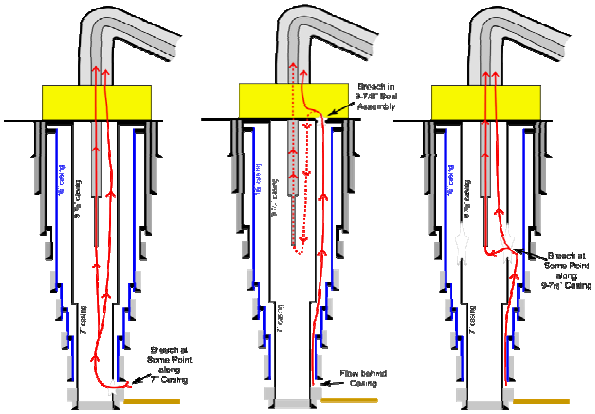
Finally, the plug and abandonment of the well by BP following BOEM guidelines in October.



And what about the oil flow?

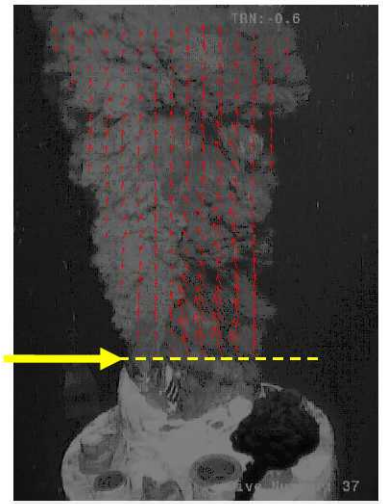
- **From the earliest days, government teams provided instantaneous and cumulative flow results.**
  - Hampered by limited instrumentation and uncharacterized BOP.
- **DOI-funded teams attempted to predict flows using the following:**
  - Reservoir-depletion modeling
  - Flow visualization
  - Well-flow modeling

Simulations performed evaluating a variety of flow paths



PIV Applied to June 3rd Flow

Velocity calculated here
Avg disp 8.27 pixels



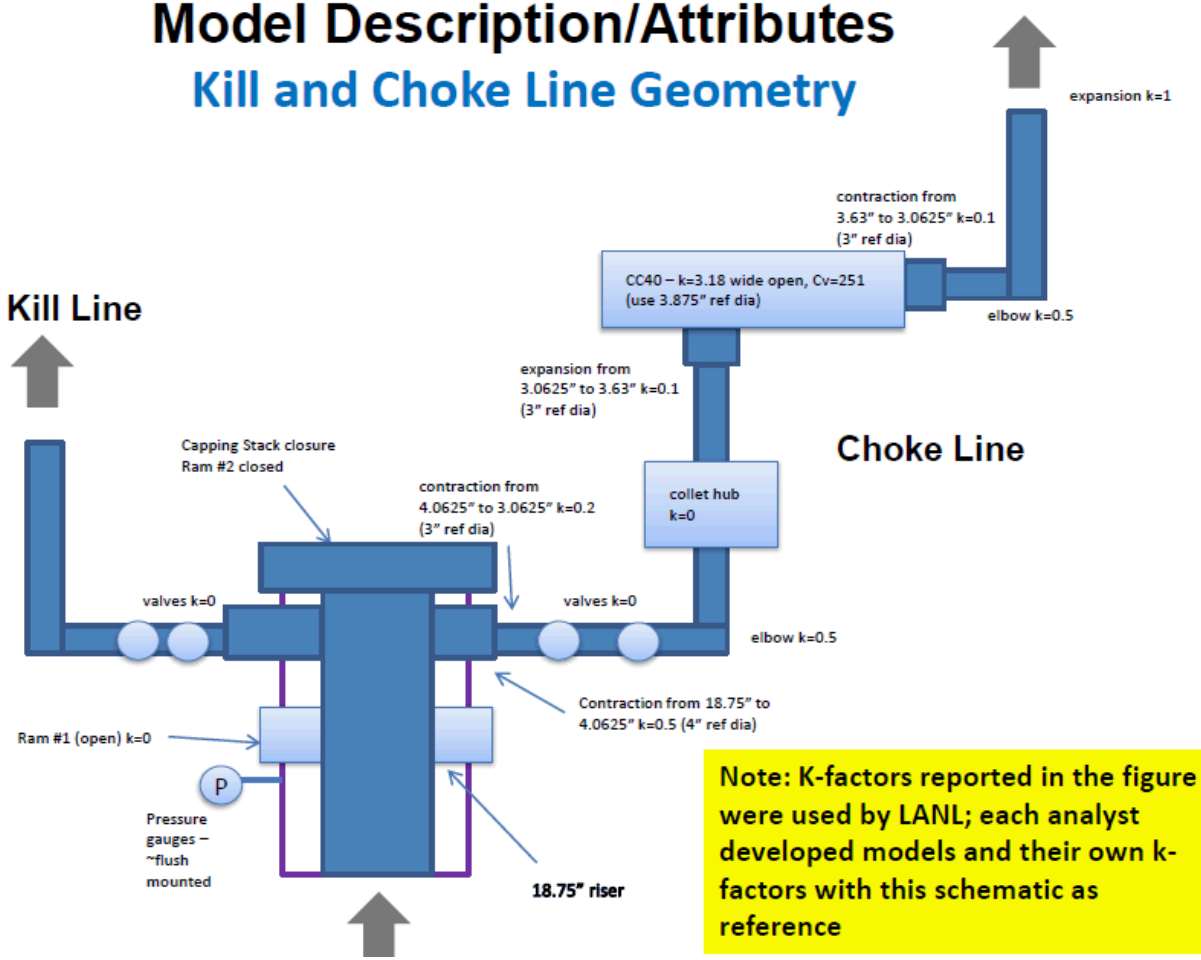
- **The DOE-NNSA teams modeled the flow during well shut-in:**
  - Used the Capping Stack geometry and pressure data.
  - Estimated from shut-in results earlier time flow rates and cumulative flow results.

The Capping Stack provided a known geometry through which oil flow could be computed.

Capping Stack geometry prior to being taken to well and secured to BOP; orange valves are the gate valves for "kill" line.

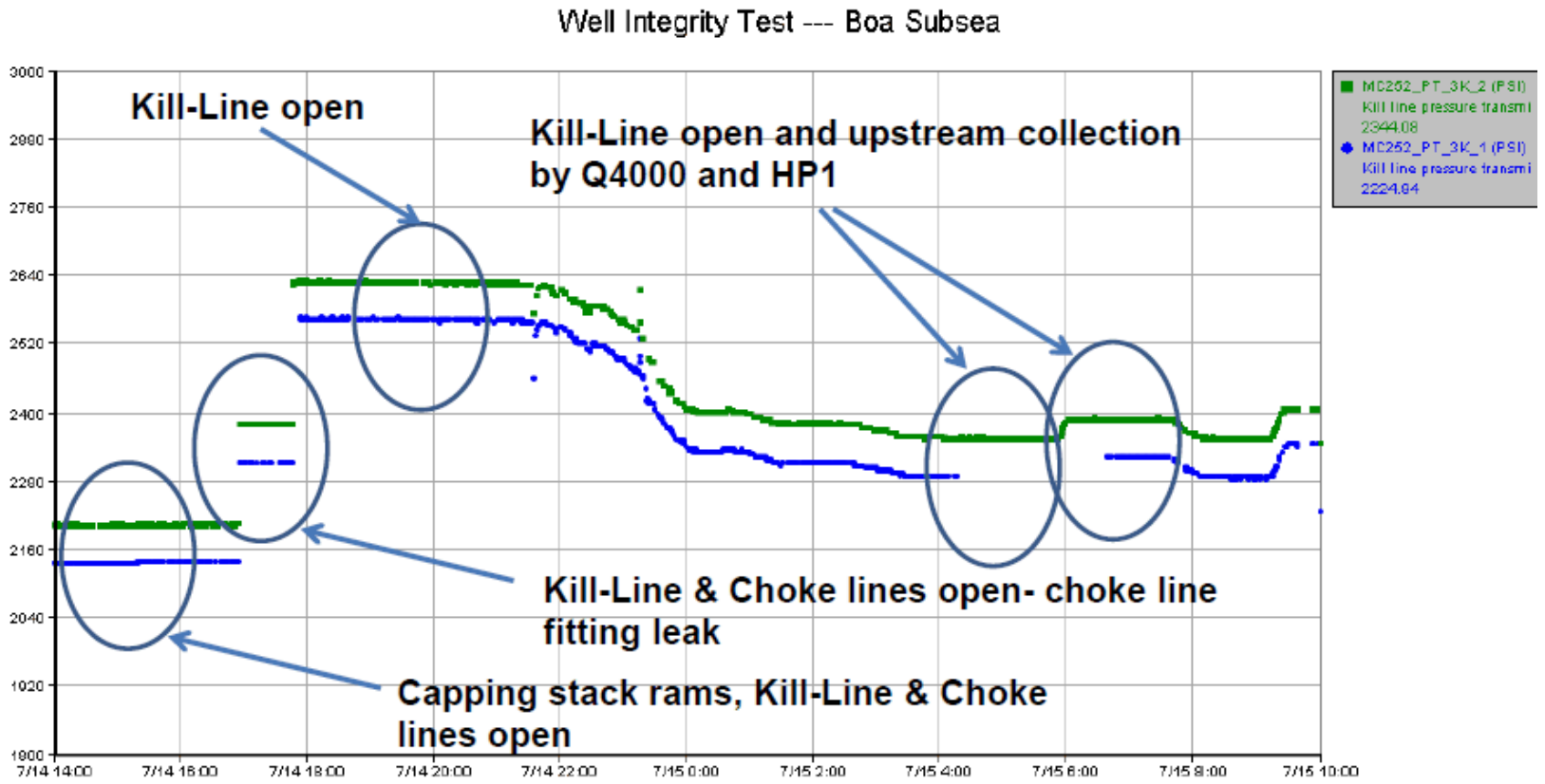
Model Description/Attributes

Kill and Choke Line Geometry



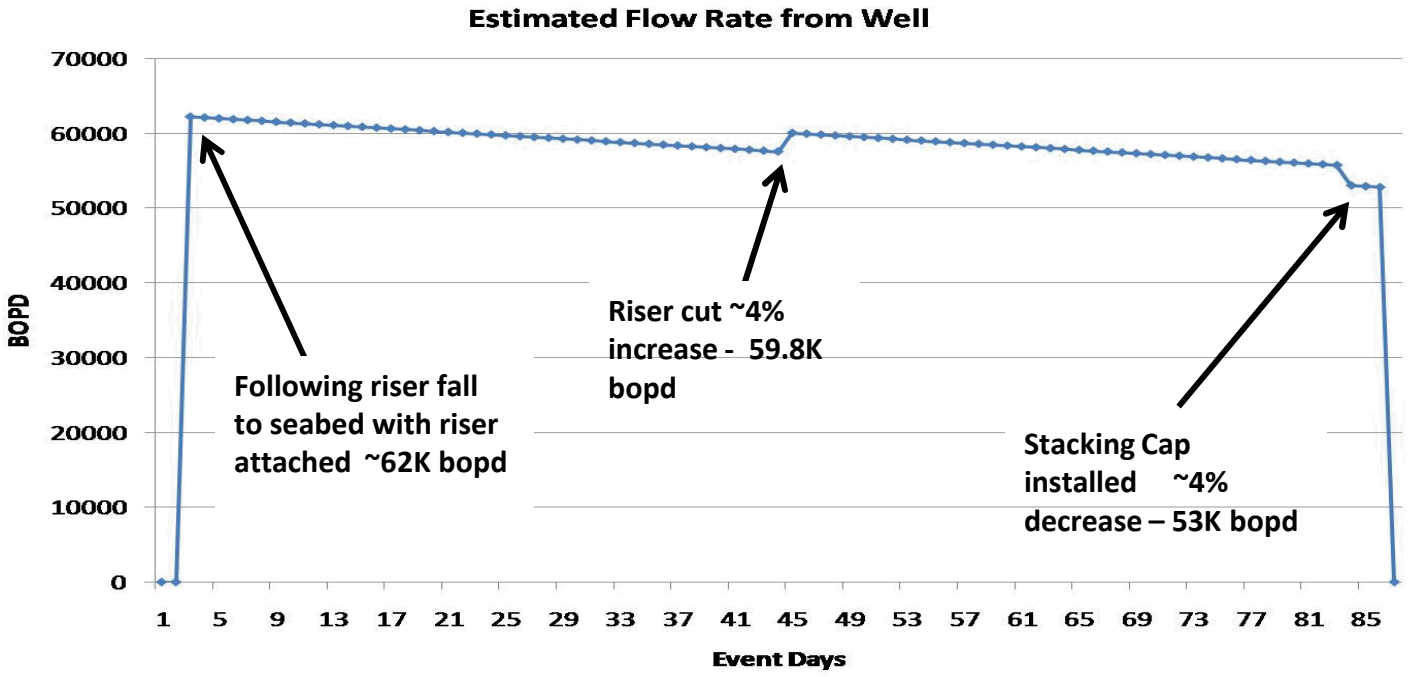
Note: K-factors reported in the figure were used by LANL; each analyst developed models and their own k-factors with this schematic as reference

Prior to shut-in, pressure changes resulting from flows through the choke and kill lines allowed analysts to infer consistent flow rates using several methods.

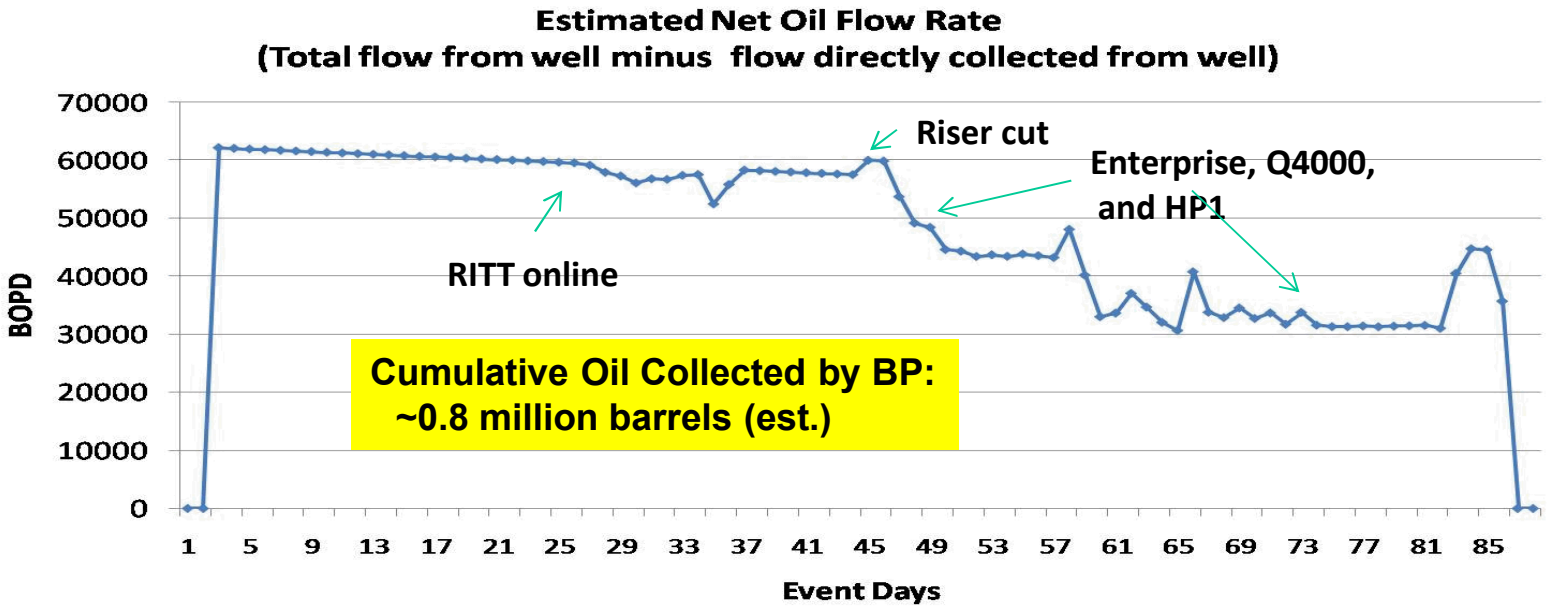


"Preferred" transducer is in green – has 10 psi DC offset not corrected in figure; evaluations performed at seabed

Government Team Flow Estimates



Cumulative Release: ~5 million barrels)



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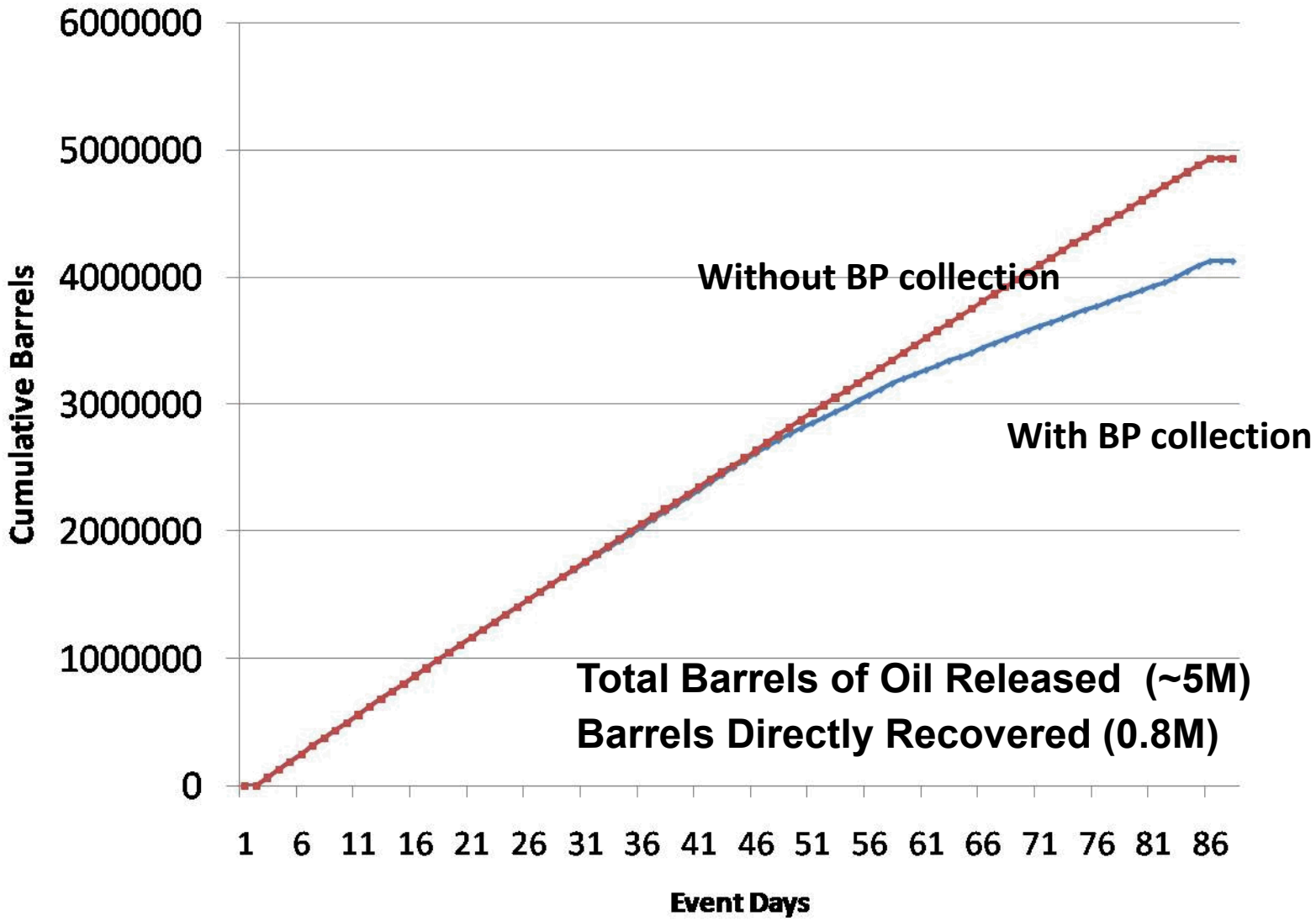
Government Team Estimates of Cumulative Flow for 87 Days



Closure: Overcoming the Deepwater Horizon accident. Everyone was involved!

Operator

US Government

State Government & institutions

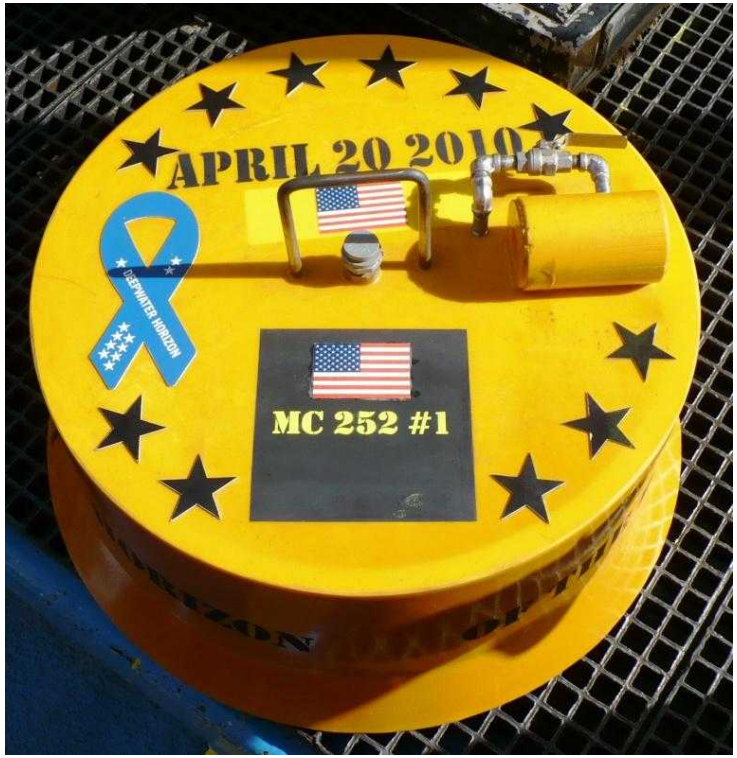
Industry Producers

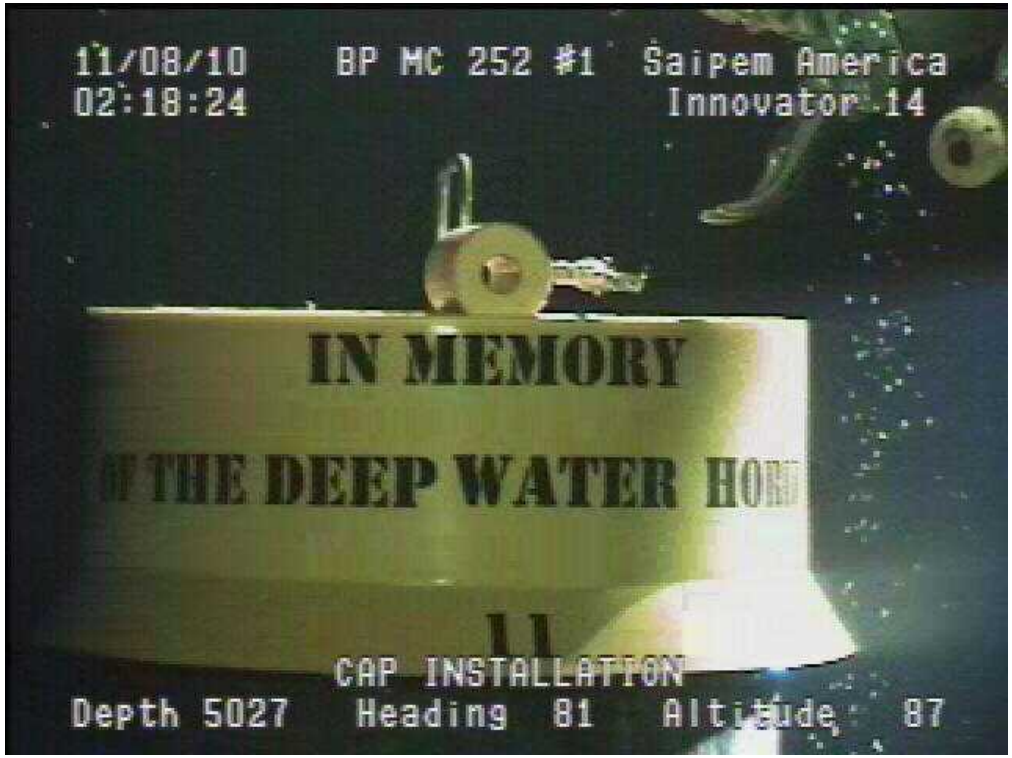
Industry Suppliers

Did the government support add value? I am convinced "Yes!"

- **Government scientists and engineers played an important collaborative role.**
  - Independent hydraulic and structural analyses
  - Diagnostic support
  - Well-monitoring methods and interpretation (such as seismic and acoustic)
  - Flow analysis
  - Design review and evaluation
- **A collaborative information-sharing environment to support decision-making was achieved.**

Lest we forget … 11 people lost their lives during the Deepwater Horizon accident on April 20, 2010.





Cap installed on the Macondo well head following “plug and kill” operations.

Questions?