Considering Technical Options for Controlling the BP Blowout in the Gulf of Mexico

Written by James Cameron
and Members of an Ad Hoc Deep Ocean Group
after meeting in Washington, D.C.
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On June 1, 2010 twenty-eight experts in marine engineering and science, as well as government and oil industry technical advisors, met at the EPA building in Washington to consider possible alternative solutions to capping or controlling the runaway well in the Gulf of Mexico.

The group included leading experts in deep ocean engineering, marine science, remotely operated vehicles, piloted submersibles, offshore oil operations and well control. Also attending were representatives of NOAA, EPA, and the Coast Guard.

Executive Summary

On June 1, 2010, at the invitation of James Cameron, a group of twenty-eight experts in deep ocean engineering and exploration met in Washington, DC. This group included representatives from marine industry, oceanography, government agencies, and ocean advocacy and represented a unique and powerful talent base focused on one purpose: to identify possible solutions to capping and ultimately controlling the runaway Deepwater Horizon well in the Gulf of Mexico.

At meetings end it was recognized that the situation was much more complicated than portrayed through the media and that the potential for making matters dramatically worse was significant. With that in mind this group recommended three near-term solutions.

1. Tap into the 8 additional 3" ports that currently exist on the BOP to draw off more oil through the second riser (2nd riser was established for the two 3" lines used for the kill shot). Using this technique should allow the capture of significantly more oil than is currently being recovered. These lines will function in parallel with the existing LMRP Cap while the new valve/cap is being fabricated. These additional lines could also be used to pump heavy mud, and then cement, in a repeat of the top kill procedure should one be attempted.

2. Replace the existing LMRP Cap with a new cap that produces a solid seal, and has a valve that can be controlled from the surface to produce the necessary back pressure for a more effective top kill procedure. The cap would be mechanically locked over the existing flange at the top of the BOP, using hydraulically actuated clamps, then filled with cement, epoxy or ferrofluid to generate a permanent seal. A rubber tube or skirt inside the cap would keep a channel clear for the oil to flow through while the sealant is injected. Variants on this cap/valve concept include a temporary or permanent expanding bladder inserted into the bore of the BOP if the bore is unrestricted with drill pipe.

3. As an alternative to top kill, it may be possible to engage the existing drill pipe with an overshot, using high frequency sonar to image within the venting oil. If sufficient unobstructed internal clearance exists through that pipe it could have a tube inserted through it. The object is to pump heavy mud into the well deep in the hole. A version of this concept that incorporates an expanding bladder cap (pipe through the middle of the bladder) would combine the best of both concepts... back pressure and deep injection of mud.

The optimal outcome is that some combination of these techniques could be used to kill the well, which is vastly superior to the current situation in which the cap system is estimated to be capturing only about half the oil, and the whole thing is vulnerable to work stoppage in the event of a hurricane. Killing the well is a 100% solution.

In addition to consideration of the Deepwater Horizon well itself, the group discussed steps that should be taken to more efficiently manage similar environmental threats in the future.

These included encouragement for the deployment of long term undersea environmental monitoring systems, the establishment of environmental baselines, and the design and development of a rapid response capability consisting of an assortment of platforms and sensors.

(Subsequent to the meeting of the task force BP revealed there are three 16" rupture/burst disks in the well, the condition of which is not known. If their integrity has been compromised any effort at a top-kill has a very low probability of success and may further damage the integrity of the well.)

First Phase of the Meeting: Establishing what was Known

The first phase of the meeting consisted of briefings and technical discussions of the history of the disaster to date, including steps taken to control the well, the current status of the well and the blow out preventer (BOP), and likely conditions within the well bore and formation. We were able to form a detailed picture of what had happened, how it happened, and what had been done to control the crisis.

Significant discussion took place to better understand flow rates and pressures within the BOP and riser, the status of blind/shear rams within the BOP, damage to the BOP and to the fallen riser, and the reasons the top-kill procedure failed.

We spent several hours understanding standard well control practices, and the specifics of this well in its pre and post accident states. Considerable focus was given to what had happened downhole and within the BOP in order to account for the current conditions that were observed. Fully aware that we were working with imperfect knowledge of the facts, we believed we were able to create a comprehensive picture of the conditions, pressures and flows.

Using investigation transcripts and other sources, Professor Bob Bea of UC Berkley provided critical information regarding casing sizes and depths, drill pipe grades, mud weights and other specifics.

With his extensive offshore drilling experience, Kim Hatfield helped us understand what might be happening within the BOP and the well bore. This allowed us to make an informed analysis and bring forward viable engineering concepts.

Second Phase of the Meeting: Potential Solutions

During the meeting's second phase we discussed what could be done to control the well and/or contain the spill at its source. Contributions from all parties included proven practices and beyond-the-box thinking.

These concepts were organized into two broad categories: "Kill or Cap the Well," and "Capture the Oil." They were meant for use in parallel with each other, and in most cases, in parallel with BP's planned actions. Lines of enquiry were not constrained on the basis of who would do what. Some of the ideas required heavy lifting of massive payloads or highly specialized drilling-related procedures, and could only be accomplished with oil industry assets (many of which are already on scene.)

However, members of the group assumed they would have a valid role in engineering design, FEA, and possibly fabrication and deployment of any specialized new hardware. Some concepts could be fabricated off site, in parallel with current activities, and delivered for BP's use.

Special consideration was given to the availability of off the shelf components or items that could be modified or fabricated on a timely basis. Although specific capabilities and vehicles available to members of the group were considered, this was not the focus of the discussion, nor did it influence our concepts or recommendations.

Analysis of the BOP

The exact manner in which the BOP failed and its internal condition is not precisely known. We understand that the pipe rams and shear rams were actuated, but did not create a seal, possibly due to the specific drill pipe which was a higher weight and grade than normally encountered, or because of obstruction(s) in the bore of the BOP. Knowing the exact nature of this obstruction is not critical to forming a plan for containment. We understand that a relatively small amount of flow restriction—thought to be approximately 800 psi—is taking place within the BOP.

We assumed that BP had done their best to regain control of the BOP, using ROVs and all their other technical resources, so there was little point in our group second-guessing this process. We understand that despite removing, repairing and reinstating the control pod on the BOP, the extent of control currently is limited to two valves and not the rams.

The BOP may have failed because a piece of casing or wellhead seal assembly were forced up from below by the blowout, and lodged between the shear rams. Another possibility is that a higher grade of drill pipe was used than the rams were designed to cut, (or a combination of the two.) The shear rams were designed to cut casing, or drill pipe, but not both together. According to testimony, the rams had not been tested on the grade of pipe used in this well. For whatever reason, the partially closed rams allowed a large volume of flow to pass through the BOP.

Two annular preventers are located in the stack above the blind/shear rams and are designed to close on drill pipe, casing, irregular shapes or even open hole. If either annular preventer had functioned and sealed around the drill pipe, the flow would have been restricted to a path up the drill pipe. From observation we know this is not the case, so either there was dual failure of the annular preventers, or they functioned and are sealed around an object that is bigger than the drill pipe, providing a flow channel between the obstruction and the

drill pipe. This is consistent with the hypothesis that a piece of casing is lodged within the BOP.

Ideas for reactivating the rams using an ROV were discussed and rejected. BP gained some control of BOP function after removing the control pod by ROV, refurbishing it at the surface, and reinstalling it. Control of at least two valves was regained and used to re-establish control of the choke-and kill lines. We don't know if BP successfully operated the rams after the accident. Based on their subsequent decision-making, we assumed they did not.

Killing the Well

Methods to restrict and control the flow of oil at the top of the BOP were considered. The general concept was to stop or throttle the flow at the base flange of the riser (after it has been cut off) in order to create back pressure. This would allow another attempt of the top-kill operation with more effectiveness.

Various techniques were considered, including caps with attached valves that would be locked to the top flange of the BOP with hydraulics and sealed securely with cement, epoxy or ferro-fluid. The objective was to gain positive control of the flow, throttle it, create sufficient backpressure to drive mud down the hole, and allow the hydrostatic pressure of the mud column to control the flow out of the formation.

We considered the possible negative effects of these concepts, such as an underground blowout or the inadvertent creation of additional leaks at or below the wellhead.

There was concern that capping the flow at the BOP or significantly raising its internal pressure to drive the mud down against formation pressure of about 13,000 psi (based on mud weight of 14 PPG at TD of the well,) might create an underground blowout at the last casing section. When it was established that the casing shoe on that casing string was at approximately 17,000' (12,000' below seafloor), this concern was deemed minimal and the value of shutting in the well was sufficient to recommend proceeding with a restriction/top kill approach.

To prevent massive spillage if a hurricane forces the disconnection of the LMRP (lower marine riser package) cap, we recommend that, if possible, a top kill or other process to shut in the well be attempted.

Because of the risks involved we rejected disconnecting the BOP from the wellhead, or the LMRP upper half of the stack from the lower half of the stack in order to replace them or insert valves. The status of the drill pipe within the BOP was discussed. (NOTE: the riser has been sheared since our

discussion took place, but we do not know the condition of the drill pipe, whether it fell downhole or remains inside the BOP. High frequency sonar mounted on an ROV should be used to image the pipe's position within the top of the BOP, if it is still there.)

We considered that if the pipe is in place (held by the rams), it might be possible to engage it with an "overshot," pump heavy mud deep into the hole to build up hydrostatic head pressure, and stop the flow. However we rejected this concept because we understand that the drill pipe only extends 3000' below the BOP, meaning the mud would be injected 10,000' above the bottom of the well bore.

If a large enough bore still exists within the pipe, it may be possible to insert coiled tubing through it. The tubing could be used to pump heavy mud into the bottom of the well bore and re-establish circulation. The downside of this approach is that complex operations need to be carried out with the well venting at full rate into the ocean. If, however, a significant amount of the flow can be recovered lower in the BOP (by the addition of more 3" lines, as discussed below) this might be considered a worthwhile approach if it can be accomplished quickly. It would offer greater opportunities to assess the conditions downhole, and provide a higher probability of success for controlling the well than a top kill.

If the drill pipe fell into the borehole when the riser was cut off, it will be difficult, perhaps impossible, to get a subsequent pipe down the well. In any event this type of operation is outside the scope of experience of this group (w/ exception of Hatfield) and BP has better information to judge the effectiveness of this procedure.

If the drill pipe has cleared the BOP when the riser was cut off, other options for stopping/controlling the flow may be possible, such as inserting an expandable bladder into the top of the BOP. This method of blocking the flow is proven technology and is within the experience of members of this group.

Further development of this idea is recommended in the event the LMRP cap must be removed for an oncoming hurricane, clogging with ice, or for repair. It would provide a quick means of blocking or partially blocking the flow at the top of the BOP. The bladder could be expanded with fluid, making it removable, or expanded with two-part epoxy for a permanent plug. This group has specific knowledge of these materials and their use under similar pressures and temperature conditions to those in the BP well. It could be prepared as a standby solution, and put in place if removal of the LMRP cap is necessary. Reasons for removal of the LMRP cap would be: a hurricane forcing the cessation of surface activities, clogging with hydrate, or repair.

To minimize concerns about exceeding allowable pressure inside the BOP, or down the hole, a bypass pipe could be integrated into the bladder. A valve in the pipe would keep the flow below the maximum allowable pressure and minimize the oil spilling into the sea.

A more comprehensive solution would be an expanding plug with a valve in the bypass pipe connected to a riser. Oil could be recovered without spillage, and if the recovery ship moves off station, the plug remains in place, venting only as much flow as is necessary to keep pressures nominal. This approach also could be used in parallel with a new top-kill procedure. It is superior to the current strategy of open venting of the well if the recovery ship moves off.

If they can be de-mated from the riser in the event the ship must move, the above-mentioned sealed caps (sealed with cement, epoxy or ferro-fluids) could also be used in this manner. The valve would stay in place, reducing the flow to a minimum, until the ship returns.

Ideas for positively controlling the flow were proposed for use in conjunction with the choke-and-kill lines to perform a repeat of the top-kill. (The need for a junk shot to further restrict flow and generate back pressure above the choke-and-kill lines leads to the assumption that insufficient backpressure was created for the top-kill to work effectively.)

The junk shot is clearly an ineffective way to accurately control pressure in the top of the BOP. We concluded that if the decision to inject golf balls and chunks of tire into the BOP made sense, there was a need for greater flow restriction or back pressure than that provided by the obstructions in the bore of the BOP and the restriction at the riser crimp.

It seems logical to create a controllable means of throttling the flow/ pressure to a value above that provided by the existing blockages, but below that of a fully capped BOP.

It is unclear why this is not being attempted and we recommend it be considered. (If top-kill was a good idea a week ago, what has changed to make it undesirable now—especially if a way of creating the necessary back pressure can be found to make it more effective?) We assumed that the maximum allowable internal pressure was not achieved or sustained, or the junk shot would have been unnecessary.

An attempt to repeat the topkill with better flow control and back pressure was considered viable, because BP's proposed plan (LMRP cap) will not capture all the flow. In fact, now that it is in place, it is clear that a large percentage of the flow is venting around the cap. (A worst case analysis of present conditions: if the overall flow doubled when the riser was cut off and the restriction thus

removed, and the cap is now capturing half the oil, the net improvement from a week ago is zero. It's probably not this bad, but we don't know it isn't this bad.)

Since the hurricane season began on the day of our meeting, this LMRP cap was deemed unacceptable as a stand-alone solution. A plan should be developed to kill the well prior to the relief wells projected-but-uncertain completion in August.

We concluded that it is probable that the top-kill failed because of insufficient back pressure due to an unfavorable relationship between the diameter of the choke-and-kill lines and the cross sectional area of the opening through the BOP, which caused most of the mud to be vented upward. This attempt did, however, have the detrimental effect of washing out the crimp in the riser and allowing higher flow rates from the well due to less restriction at that point.

After learning that there was only a relatively small differential between internal pressures at the top of the BOP and the bottom of the BOP, we assumed that BP engineers were relying on the crimped riser to generate sufficient back pressure to perform the top-kill. We also assumed that the junk shots were meant to raise the back pressure by lodging either within occluding structures inside the bore of the BOP, and/or by lodging within the riser at the crimp.

It was reported that flow from the well might have been reduced during the top-kill, which suggests some limited effectiveness of the mud column down the well. At some point the flow increased to previous levels, suggesting that recharging in the formation reversed this. Better control of flow restriction/ back pressure above the BOP may have driven more mud down the well and made the procedure more effective.

It is critical to know if BP was able to achieve close to the maximum pressure within the BOP that they deemed safe— reported to be 8,000 psi. If BP were able to sustain pressures approaching this limit on the prior attempt, then further attempts to perform a top-kill are pointless. If, however, there is a significant gap between the pressure they achieved and their maximum safe pressure of 8,000 psi, then restricting the flow at the top of the BOP to create back pressure in a controllable manner could allow a successful repeat of top-kill.

Cmdr. Greene, USCG, provided the figure of 8,000 psi. He could not confirm if this figure was absolute pressure or differential pressure relative to ambient pressure of the water column. We assumed that this figure was the greatest internal pressure that BP felt comfortable using—because of the risk of potential failure of the pressure integrity of the BOP, or of the riser upstream of the crimped restriction, or failure of the casing seals, the casings themselves, the formation wall or the creation of new leaks at the surface or a possible underground blowout.

Leaks at or below the seafloor would be extremely difficult to contain. In the absence of knowing all the data available to BP engineers, it was deemed prudent for us to accept that figure and recommend plans that would work within the limits imposed by BP.

If the maximum allowable pressure during the top-kill was predicated on the failure threshold of the short length of riser upstream of the crimp (with its one-inch wall thickness) as the weakest link—rather than on potential failures lower in the well— this could be revisited, now that the riser has been sacrificed.

If the next weakest link is the flex joint (say 9000 psi for sake of argument) and the delta between achieved pressure in the prior top-kill and the 8000 psi maximum limit was 1000 psi, then the new delta available by valving of the flow would be 2000 psi. We wondered if this was a significant enough change to make a second top-kill viable.

We don't know why BP decided not to attempt to attach another BOP section on top of the existing BOP, but instead chose to create a loosely mated LMRP cap with no real sealing capability. We suspect that this was done to create a reliable quick disconnect in case the ship needs to move off station in a hurricane, and/or because the seal might need to "burp" when there are further methane kicks. Another possibility is that the mass of an additional hard-mounted LMRP (200+ tons) might cause a weakened bottom joint to fail.

We believe that bending forces applied when the *Deepwater Horizon* burned and drifted out of control must have significantly stressed the bottom joint—and the BOP may be structurally compromised at its base.

Shortly after the explosion, the DPS (Dynamic Positioning System) on the rig failed leaving the rig floating without control in winds and ocean currents. (Although there was sufficient time to get tugs on scene, we could not find images of tugs keeping the rig in position. The USCG tentatively confirmed that no tugs were used.)

This means that the ship's drift was arrested solely by tension on the riser and possibly the drill pipe. This would have bent the flex joint to its maximum limit and put enormous lateral loading on the top of the stack, with the highest stress point at the bottom connection just above the base plate. The BOP would have been a 45-foot long moment arm, with the entire force of a drifting drill rig applied to one end, generating powerful bending loads.

The Emergency Disconnect System (EDS)—designed to automatically disconnect if the riser deflected more than 4 degrees off vertical at the flex joint—was in place to prevent this scenario, but failed to do so. The EDS may have been disarmed at the surface. According to eyewitness testimony

an attempt was made to fire the EDS manually from the surface after the explosion, but the blast may have severed the control-data link with the BOP.

For more than a day, the drifting ship exerted enormous bending forces on the base of the BOP, possibly in a circular manner as currents changed. These forces flexed the BOP in different directions, further weakening it. Knowing the current and wind conditions during that time period would allow calculation of those forces, a better understanding of how close the structure came to failing at its base, and if stress cracks can be expected.

Consideration should be given to the compromised structural integrity of the BOP in ongoing planning. When the BOP is ultimately recovered, its bottom structure should be examined for yield and cracking.

The riser ultimately failed in tension about the time the ship sank. We note that the fire was fed by fuel from the well during the ship's rolling departure from the surface and that an enormous upwelling of un-ignited oil was visible beside the hull. It suggests that the riser had parted, venting oil near the surface. In this case the riser was only supported by the drill pipe, which continued to feed fuel to the fire. It means that the pipe in the well is continuous and can hold a head of pressure sufficient to force oil to the ocean's surface.

Now that the riser is cut off, accessing the drill pipe may be possible. Even within the visually opaque vent of oil, high frequency multi-beam sonar mounted on an ROV should be able to image the position of the pipe inside the bore of the riser stump. An overshot could be used to connect the pipe to surface pumps and recover oil, or drive mud deep into the well, if it has not been completely crimped by the severing operation.

The danger of creating high pressures within the well by blind-capping the BOP or via a high pressure top kill procedure were discussed. An underground blowout at these higher pressures was considered, and ultimately deemed not a critical risk, because it was reported that the final casing string (9 7/8 – 7 inch tapered) only extends about 1000 feet below the shoe of the 9 7/8 cemented casing (i.e.: at 12,000' below BOP). There was concern that, had there been more length of open hole, an underground blowout higher in the formation (i.e. at 10,000' below BOP) could later cause a blowout of the relief well when it hit that unexpected highly pressurized zone. But because the cemented casing extends to 12,000' below the BOP, an underground blowout at that depth should not effect the relief well, providing its mud is balanced sufficiently heavy. Finally it was decided that BP, with more data available than this group, had considered the risks and decided to proceed with the top-kill up to a maximum pressure of 8,000 psi.

Capturing the Oil

Our second path of discussion followed the idea of improving the capture of vented oil at the well site. It was assumed that the LMRP cap would not successfully capture all of the flow from the BOP and that this would need improvement. One major flaw of the LMRP cap is the poor ability to handle large pressure differentials created by going from a larger flow area to a much smaller one. (We see now, via ROV camera feeds, the amount of oil venting from the unsealed cap.)

It was suggested that connecting directly to more of the ten available 3" valve ports on the BOP and establishing a number of additional lines to pump off the oil—through a new manifold on the seafloor—could help bring the oil to the surface in a controlled way and increase the effectiveness of the LMRP cap. We concluded that given the current configuration of valves, only two additional 3" lines could be plumbed, but we recommended that this be done. It would double the volume of oil being pumped to the surface this way.

We were intending to recommend that this be combined with using the existing choke-and-kill lines to pump oil to the surface, but it was revealed in Kent Wells' briefing of Tuesday, June 1, that this was already being planned.

We recommend adding the two additional 3" lines because it will double the amount of oil being extracted from the BOP and may lessen the loss at the LMRP cap. In addition it will provide a separate path for capture of oil, which provides redundancy if there are failures of pumps or other problems.

Once in place, these additional lines could also be used to pump mud down, doubling the volume—without increasing pressure—for any subsequent top-kill procedure. It would also allow getting the cement in twice as fast.

There are 6 additional 3" ports on the BOP, presently without valves, which could also be used. Techniques to hot-tap these ports using an ROV presumably are available to BP. In theory a total of 10 3" lines could eventually be drawing oil from the BOP, 5 times the current plan. These lines could be used in a new top-kill procedure to pump heavy mud down, at 5 times the volume of the previous attempt, but without increasing the pressure. This, coupled with fine control of backpressure using a sealed cap and valve, would vastly improve the likelihood of success.

Third Phase of the Meeting: Research Needs

Although not within the proposed scope of the meeting, it was decided that this unprecedented gathering of deep ocean experts offered an opportunity to create a framework for the research and data gathering essential to quantify the impact of the greatest environmental disaster in US history. The group turned

its attention to discussing how such a complex research program, comprising hundreds of investigators at scores of institutions, might be organized.

The first priority was the need to create a centralized and widely accessible database of all data, samples and images that have been gathered to date, across all the institutions, into one comprehensive baseline. Currently it is a patchwork residing with many different researchers, gathered at different times with different instrumentation. Until there is a comprehensive baseline, new data can't be effectively compared for analysis.

The *Deepwater Horizon* incident is not the first or last environmental catastrophe to occur in the deep sea or along our coastlines. As such, we encourage forward planning that will identify potential threat areas as well as design, develop, and deploy technologies to rapidly detect, assess and mitigate environmental damage and human impact.

The importance of long term environmental observations in order to identify and model natural cycles cannot be over emphasized. The same holds true for the collection of base-line information regarding marine ecosystems in the water column and on the sea floor.

We recognize that many of the recommendations have already been identified and that some are currently being deployed. We also recognize that although much of the necessary technology exists, the ability to design and deploy integrated systems is extremely limited by availability of funds.

Base Line

In order to most accurately establish the impact of any given catastrophic event we must first document and understand the pre-event character of the particular marine environment. In order to understand the "after" picture, we need to understand the "before." Base line studies are underway, but they are 'islands' of individual science projects rather than an aggressive and comprehensive effort.

Long Term Monitoring

This involves a system of fixed and mobile platforms (buoys, moorings, drifters, AUV's, robots, space-based) that provide long-term environmental observations over wide-areas. Among other things, these long-term observations will provide time-series data critical to establishing predictive models. Components of ocean observation systems are being designed and deployed at various locations, but continued funding is critical.

Rapid Response Capability

A suite of technologies (autonomous, remotely operated, drifting, and fixed

platforms) that can be rapidly deployed (air dropped, small craft, etc.) to provide real time environmental information to environmental and political decision-makers. The data from these systems will be compiled and distributed from a central Environmental Threat Center. Although some elements exist, no such comprehensive capability exists today.

Public Involvement

In each of the above, significant effort should be made to engage the interested public and educational communities.

Conclusions and Recommendations

Regarding BP's post-accident response, our general conclusion is that BP have assets on scene sufficient to deal with the problem. BP's expertise is excellent at the engineering level, and the post-incident decisions made to date are, for the most part, correct, at least regarding well control, however we believe that more needs to be done.

Although the media have given the impression of sequential processing of the problem as each new procedure is attempted, it is clear that sufficient parallel processing has been applied to solve the problem on several fronts.

However, external advisory support and analysis from the deep ocean community should have been sought out, both by BP and government, at an early stage.

The transparent flow of information from BP to responding agencies and from the marine science/engineering community to the government would have helped enormously. Obtaining critical information on flows, pressures and status of the well was beyond arduous and thus much of it was estimated or inferred.

Going forward, BP should avail itself of the analytical and engineering support offered by the deep ocean community, which is highly expert in deep vehicle design and operation, and in deep ocean operations at depths greater than the well site.

BP should consider restricting BOP internal pressure at the top flange and then repeating the top-kill, because the LMRP cap is subject to leakage and forced removal in a hurricane. This would involve creating a new cap or plug containing a surface controlled valve. The valve would be used to meter the flow, maintain enough back pressure in the BOP and give the top-kill a greater chance to work. The new cap/plug would make a high pressure seal to the upper flange, as opposed to the LMRP cap's "loose seal."

A variant on this idea is using the existing drill pipe, already in the well, or an

additional pipe or tube inserted through it (or replacing it) to inject heavy mud all the way to the bottom of the well and attempt a kill that way. BP should be asked if they have analyzed this. The opaque flow of the oil will require the use of high frequency multi-beam sonar to image the pipe's position inside the BOP.

To increase capture of oil, BP should add more 3" lines (same as the choke and kill lines) to take advantage of the multiple valve ports on the stack. This would require significant work with ROVs, but could happen after the LMRP cap is in place. Two and possibly as many as eight 3" lines could be added. These lines would pump more volume of oil to the surface without relying on the LMRP cap. They will also relieve the flow at the LMRP cap and provide backup if it fails or needs maintenance. In addition, they could be used to pump mud into the well bore at high volume in a second attempt at a top-kill. Combined with higher back pressure and fine control of BOP internal pressures from the proposed valve/cap, this could insure success months in advance of the relief well.

A major flaw in the current LMRP cap strategy is that it depends on the ship holding station without interruption. If a hurricane forces the ship to move, the well will vent without restriction into the sea. We predicted during the meeting that the flow would increase significantly when the riser was cut off, and it has—more than the predicted 20%. This rate is the new normal any time the LMRP cap is removed because of weather or loss of function. With a minimum of two months required to complete the relief wells, we recommend that another attempt to kill the well be made soon.

BP has assets on scene sufficient to deal with the control of the well. The deep ocean community has vehicles that could assist, but they are unnecessary for work directly at the well, and integrating working styles with the offshore ROV operators already on the scene would be counter productive.

However, assets like ROV's, 3D cameras, and manned submersibles from the deep ocean community should be employed by government agencies immediately to independently image and monitor the site and the midwater and benthic communities. Quantitative optical imaging in 3D and from uncompressed sources could be used to monitor flow rates. Acoustic volumetric monitoring similar to what has been accomplished at deep-sea hydrothermal vent sites could be utilized. Right now the government is relying on the perpetrator's poor-quality surveillance video of the crime scene.

Commander Greene of Coast Guard assured us that all command decisions were being made jointly between BP and USCG. But this can only truly happen if Incident Command has an independent flow of data and imaging, to make informed decisions. Currently it does not. We recommend independent

imaging and data acquisition in situ within visual range of the work as it proceeds. This would allow the government to monitor progress, leakage, and scan for additional leaks and hazards, as well as have a data set for accident investigation, independent analysis of well control efforts, and flow measurement.

Coordination of all vehicles on the bottom is critical so as not to impede the critical work at the well site, but can be done. This group has extensive experience in operating multiple vehicles, both piloted and ROV, within a small theater of operations. Piloted vehicles and fiber-spooling vehicles could approach the well by traversing across the bottom from a deployment point outside the cluster of ships directly over the work site, so as to not interact with BP's ROVs, tethers, and risers.

In addition to independent imaging and monitoring of the site, the responsible agencies should look to our group to assist with incident investigation. *Phoenix* has performed search and recovery operations for the US Navy under Sup/Salv. *Lightstorm*, working with the Russian Academy of Sciences Mir research subs, has carried out exterior and interior forensics studies at *Titanic* and *Bismarck*. (Both wrecks are at much greater depths than the blown out well.) Woods Hole has decades of experience with deep-sea surveys, bottom mosaics and marine archeology including the *Titanic* wreck site and Challenger debris field. There is no better capability anywhere in the world.

Creating a definitive seafloor survey of the site, including the wreck of the *Deepwater Horizon*, will be a critical part of the accident investigation. Members of this group have extensive experience operating small fiberspooling ROVs inside shipwrecks hundreds of feet and several decks away from the entry point. It may be possible to recover valuable data from the *Deepwater Horizon* that could assist in understanding the accident. A comprehensive interior and exterior survey of the wreck should be performed as a basic part of the investigation. Our experience with wrecks is that "the steel does not lie." *Deepwater Horizon* holds many answers to urgent questions.

Many of the people in the room will be involved in studies to determine the damage to the environment below the ocean's surface. There was a strong level of commitment and desire to work cooperatively in an unprecedented way. Typically these institutions organize vertically under their funding agencies (Navy, NOAA, NSF and others) and work in an uncoordinated fashion. Dealing with the aftermath of the biggest environmental disaster in US history will require unprecedented coordination; all present were eager to work within this framework. Craig McLean of NOAA offered to function as a pro-tem hub for that effort, specifically in creating a master list of assets and capabilities.

One example of this kind of coordination is the need to establish a centralized database for existing Gulf samples, imaging, and research currently residing within many institutions and researchers. What the conditions were before the spill and how much good data exists is critical generating a baseline for the upcoming studies. It will also be important to standardize the instrumentation, regardless of the vehicular platform, so that the same types of data are coming in from all measurement sites.

Different institutions have different ships, ROV's, AUV's, manned subs, and deep-sea capabilities, so it will be important to cast each one in its right role.

We also concluded that this group represented an excellent nucleus for a Rapid Response Team to deal with deep ocean incidents environmental or otherwise. (Such as the search still underway for the Air France black box.) There are precedents for this in earthquakes, submarine rescue, and aircraft disasters. The team would be international and have a webbased inventory of private-public sector deep-sea scientists, technical systems and scientific packages. It would have a central command structure. It would be an independent body that governments could call on for high-resolution imaging and scientific accuracy. It was agreed to follow up on this idea; one of our members offered to host a meeting on the subject at his institution.

We are finished with regard to our recommendations on the well control and oil capture task (unless specific recommendations are adopted and create ongoing engineering or execution roles for some of the members), but we believe that this is just the start of the conversation for the coordinated research, site survey, independent site monitoring, and rapid response concepts.

In summary, this is a group of highly motivated, deeply experienced individuals who want to work together to create something unprecedented and of enormous benefit to the nation's security, scientific understanding, and economy.