BP'S PRELIMINARY RESPONSE TO THE FLOW RATE AND VOLUME ESTIMATES CONTAINED IN STAFF WORKING PAPER NO. 3

This paper provides BP's initial comments on the portion of the October 6, 2010 staff draft working paper entitled "The Amount and Fate of the Oil" (the "October 6 Staff Draft"), that discusses the estimated flow rate and total volume of oil released from the Macondo well.

In the wake of the Deepwater Horizon accident and oil spill, BP has launched the largest oil spill response in history. BP also set aside a $20 billion claims fund while waiving the $75 million cap under the Oil Pollution Act of 1990. BP is steadfastly committed to being a good member of the Gulf Coast community, and its actions reflect that fact.

Now that the well has been capped, one of the issues to determine is the amount of oil that flowed from the Macondo well. As we look to the future, it is important to have as accurate as possible an estimate of the total volume that flowed from the well. This information is crucial to understanding the environmental impact, shaping appropriate remediation plans, and assessing the legal consequences of the event. A variety of important factors affected the oil flow in complicated ways, and many of these factors—and thus the flow rate—changed significantly over time. Achieving a reliable estimate is thus an enormously important and complex technical challenge.

BP has reviewed the various discharge estimates and analyses discussed in the October 6 Staff Draft, including the estimate released publicly by the Department of Energy ("DOE") and the Flow Rate Technical Group ("FRTG") on August 2 (the "August 2 DOE/FRTG Estimate") that approximately 4.9 million barrels of oil flowed from the Macondo well, and approximately 4.1 million barrels were discharged into the Gulf.[1/] As discussed below, the August 2 DOE/FRTG Estimate and other similar estimates are flawed. They rely on incomplete or inaccurate information, rest in large part on assumptions that have not been validated, and are subject to far greater uncertainties than have been acknowledged. As a consequence, it is highly likely that the August 2 DOE/FRTG discharge estimate and similar estimates are overstated by a significant amount. For the same reasons, the statement in the October 6 Staff Draft that a consensus is emerging that roughly five million barrels of oil were released by the Macondo well is both premature and inaccurate.[2/]

Although, as set forth below, the deficiencies of previous flow rate estimates and analyses are evident, a reliable estimate cannot yet be developed because several key pieces of information have been and remain unavailable, including information concerning the Blow Out

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1/ The key environmental metric, of course, is not the amount of oil that flowed out of the well, but the amount of oil discharged into the Gulf. Although the total quantity of oil released from the well is uncertain, it is known that approximately 850,000 barrels were piped to and contained by BP in vessels on the surface.

2/ National Comm. on the BP Deepwater Horizon Oil Spill and Offshore Drilling, THE AMOUNT AND FATE OF THE OIL, Staff Working Paper No. 3 (Draft) (Oct. 6, 2010) at 16.

Preventer ("BOP"), riser kink, pressure gauges, capping stack, and reservoir core samples, all of which are currently in the Government's possession. BP fully intends to present its own estimate as soon as the information is available to get the science right. BP and the Unified Area Command have permanently capped the well, and BP's efforts continue to restore the Gulf. There is no emergency that requires a rushed quantification based on incomplete or doubtful information. With the restoration work ongoing, it is now appropriate to focus on the task of assembling all the necessary scientific data to estimate the total flow as accurately as possible.[3/]

As part of BP's work to estimate reliably how much oil was discharged, it would be useful to understand the bases for the estimates and analyses already in the public record. Even though BP and other parties have requested this information, many of the important details underlying those estimates and analyses have not been made public. For example, neither the DOE nor the FRTG has released all of the data and calculations necessary to understand and evaluate the bases for the August 2 DOE/FRTG Estimate. Similarly, the FRTG has not released information required to understand the calculations underlying any of the estimates it released prior to the August 2 DOE/FRTG Estimate. Nor, to the best of BP's knowledge, have any of the DOE or FRTG estimates and analyses been subject to peer review and critique by those with a full understanding of the technical aspects of hydrocarbon flow through oil reservoirs, wells, and surface pipes. These are serious impediments to a reasoned scientific estimate that would be broadly credible.

The August 2 DOE/FRTG Estimate has two primary components: (i) it estimated the flow rate immediately before the well was capped on July 14 at approximately 53,000 barrels of oil per day ("bopd"), and then (ii) based on that number, and certain rudimentary assumptions about reservoir depletion, it extrapolated back to a flow rate of approximately 62,000 bopd on April 22. In other words, the Estimate assumes that the flow rate of oil decreased over time. The available evidence strongly suggests that the July 14 estimate is too high, and the flow rate on April 22 was lower, likely substantially lower, than the July 14 flow rate. The August 2 DOE/FRTG Estimate and other similar estimates ignore key facts about the reservoir-well-riser system; do not take account of important pieces of data; and appear biased toward the maximum amount of oil that could have been discharged, rather than the amount of oil most likely to have been discharged. As a result, those estimates substantially understate their own range of uncertainty and also substantially overstate the amount of flow.[4/]

BP respectfully urges the Commission to consider the facts and concerns set forth in this submission before accepting the August 2 DOE/FRTG Estimate or other purportedly similar estimates. All parties involved share a common goal of arriving at a reliable and accurate flow estimate. Therefore, BP requests that the information provided below be shared with the many

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3/ As recognized in the October 6 Staff Draft, flow estimates made before the well was capped vary widely. That experience highlights the importance, now that the discharge has stopped, of developing accurate and reliable flow estimates based upon the greatest possible body of relevant evidence.

4/ For example, the range of uncertainty identified in the August 2 DOE/FRTG Estimate is plus or minus 10 percent. As discussed below, BP believes the range of uncertainty is substantially greater.

technical personnel interested in this topic and that there be open, constructive, and collaborative scientific discussion about these issues. BP is confident that a complete, comprehensive, and rigorous analysis of the flow issue will show that less, and possibly far less, oil was discharged from the Macondo well than the amounts reflected in the August 2 DOE/FRTG Estimate. Whatever the ultimate result, all interested parties and the public will have much greater confidence in the accuracy and reliability of an estimate calculated on the basis of such a scientific process.

A. THE AUGUST 2 DOE/FRTG ESTIMATE OF JULY 14 FLOW BASED ON DATA MEASURED IN THE CAPPING STACK IS FLAWED AND INCOMPLETE AND LIKELY OVERSTATES THE FLOW

The science team supporting Secretary Chu apparently estimated a flow rate of 52,700 bopd on July 14 based on pressure readings taken within the capping stack at a time when the flow of fluid was solely passing through the capping stack's kill line.[5/] As discussed below, there are numerous reasons why that estimate is flawed.

1. Failure to Consider the Complexity of the Capping Stack Structure

First, the estimate fails to reflect the complicated internal structure of the capping stack. Any reliable estimate of the flow rate of fluid through a system of pipes must take into account the pressure drop (or loss) that occurs when fluid flows through pipe fittings, transitions, elbow joints, and the like (the idealized loss associated with a particular fitting or joint is often referred to as the "K factor").[6/] Typically, K factors, which are publicly disseminated, account for the effect of the particular fitting based on the hypothetical assumption that the fitting is preceded and followed by a substantial length of straight pipe. That was not the case with the capping stack; the configuration of the components through which the oil and gas actually flowed was much more complex. Specifically, the pipe elements were close to one another and the flow had to navigate two right angle turns in close proximity. The resulting additional turbulence was not accounted for in the science team's estimate and would have led to a greater than expected pressure drop for a given flow rate.

2. Failure to Consider the Effects of Two-Phase Flow

Through most of the well system, including the flow through the capping stack, the flow consisted of both oil and gas, often referred to as a "two-phase flow." The pressure drop that occurs when two-phase flow travels at high velocities through complex geometries like the capping stack's is very difficult to predict, essentially because of the interaction of the heavier and lighter phases. BP's understanding based on information provided by the Government science team is that the August 2 DOE/FRTG Estimate fails to account adequately for this type of two-phase flow behavior, and that the team has acknowledged this failure as a source of error.

5/ October 6 Staff Draft at 14.

6/ October 6 Staff Draft at Appendix 1.

A careful study of the capping stack, which is in the Government's custody, to determine its actual effects on two-phase flow can and should be made.

3. Failure to Adequately Account for the Temperature of the Flow

The temperature of the flow through the capping stack affects flow rate estimates based on pressure measurements, making it critical that the most appropriate temperature be used. The Government used a temperature of 180 degrees Fahrenheit ("°F") in its estimate. Based on well thermal and hydraulic modeling, the likely temperature was at least 200 °F—or an increase of at least 20 °F—which could have reduced the flow rate.

An accurate and reliable analysis of the flow rate through the capping stack must account fully for the issues discussed above. These issues, when combined, would have the potential to reduce significantly the flow rate calculated from the measured pressures.

B. THE AUGUST 2 DOE/FRTG ESTIMATE'S CONCLUSION THAT THE FLOW DECREASED OVER TIME IS FLAWED AND THE ESTIMATE OVERSTATES THE FLOW AS A RESULT

1. There Were Substantial Early Impediments to Flow

A central assumption of the August 2 DOE/FRTG Estimate is that the flow decreased over time. BP's understanding, based on the limited data available, is that the estimate of approximately 62,000 bopd on April 22 essentially assumes that the only factor determining the change in flow rate over time was the depletion of the reservoir, after allowing for a small (approximately 4 percent) change due to cutting the riser. This assumption fails to account for the existence and impact of many significant flow impediments and for changes to those impediments over the course of the incident. Such impediments included the following:

a. In the early days of the incident, the blind shear ram, certain variable bore rams, and annular preventers were actuated within the BOP, impeding the flow out of the well by reducing the cross-sectional area through which the fluid could flow.

b. There was a large kink in the riser at the top of the BOP through which the fluid had to flow. The kink acted as a choke and impediment to flow, especially early in the incident.

c. The drill pipe broke and pieces lodged in the BOP and kink, and a section of the riser was crushed, all of which lessened the area through which the oil and any debris could flow and thus impeded flow by significant amounts.

d. Furthermore, while investigation continues into the status of the cement in the aftermath of the accident, it is possible that cement remaining in the wellbore and cement debris from the incident inhibited flow from the well, particularly in the period immediately following the accident.

Individually and in combination, these flow impediments lowered the flow rate at the outset of the discharge, likely by a substantial amount.

2. The Impediments to Flow Decreased Over Time

The August 2 DOE/FRTG Estimate also fails to consider that the continuing flow of fluids and entrained solids (including sand) eroded these impediments to flow. As the impediments eroded, the flow rate increased. For example, initial examination of the BOP indicates that components of the BOP's rams and annular preventers, which restricted flow, degraded during the course of the incident due to the continued flow through them. Similarly, the video of that examination appears to show "channeling" in the walls of the BOP around the blind shear rams, suggesting that the fluid eroded the walls, thereby creating additional passages over time. These are among the many reasons why obtaining access to the BOP and understanding its current state are required for any accurate and reliable flow rate analysis. In addition, the ROV images clearly show that the fluid eroded and caused leaks in the kink in the riser and that these leaks increased over time.

In sum, the assumption that the flow rate *decreased*, rather than *increased*, over time is flawed and based on incomplete information. It is also noteworthy that the assumption is inconsistent with the FRTG's earlier estimates, which increased over time.[7/] To develop an accurate estimate of the volume of oil discharged—and to account for the probability that the flow rate increased, rather than decreased, over time—it is essential that the effects of all the impediments to flow be fully considered.

Basing flow rate estimates solely on reservoir depletion without considering any flow impediments very likely led to fundamental, pervasive, and cascading errors. In particular, as explained above, flow impediments and their erosion over time would have caused the flow rate to *increase*, not *decrease.*

3. The August 2 DOE/FRTG Estimate of Flow on April 22 Is Inconsistent with the Measured Reservoir Pressure

After BP and the Unified Area Command shut-in the well on July 15, the wellhead pressure was carefully observed and monitored for 18 days, up through the "static kill." The pressure increases observed during the monitoring provided confidence that the well was maintaining its integrity and also provided key information regarding the reservoir properties, including, notably, a direct method for calculating the reservoir depletion. The pressure

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7/ The FRTG estimated flow rates in the range of 12,000 to 19,000 bopd on May 27; 20,000 to 40,000 bopd on June 10; and 35,000 to 60,000 bopd on June 15 (the higher number of this last range is based on the unreliable Top Hat pressure readings discussed below). While further analysis of the estimates is required using the most complete information available, the trend of the FRTG's estimates is consistent with the opinion of BP's technical experts that the significant flow impediments present early in the flow period had less effect over time.

measurements recorded at the top of the well, taken together with the known well depth and fluid density, allow for the calculation of the pressure at the bottom of the well (*i.e.*, the "bottom hole" pressure). When the well stopped flowing, the calculated bottom hole pressure increased slowly over time, approaching the final average reservoir pressure. The difference between the initial reservoir pressure of the Macondo well, which was measured prior to the incident at 11,850 psi, and the final average reservoir pressure determined from these pressure measurements is the reservoir depletion.

On August 3, the calculated bottom hole pressure was greater than 10,200 psi and still increasing in such a manner that industry-standard techniques predict the final average reservoir pressure to be approximately 10,600 psi. Consequently, the reservoir depletion is approximately 1,250 psi. This calculated depletion amount is significantly lower than the depletion level quoted in a draft Government science team report (1,800 psi) and the October 6 Staff Draft ("about 2,000 psi"). The August 2 DOE/FRTG Estimate relies on this incorrect depletion level to extrapolate backwards to a flow rate on April 22. As a result of this error, separate and apart from the failure to account for the flow impediments, the Government's estimates of the initial flow rates are significantly overstated.

4. Failure to Account Accurately for Reservoir Conditions

It is essential to consider the characteristics of the reservoir in making flow rate estimates. However, the August 2 DOE/FRTG Estimate does not consider the characteristics of the actual reservoir at issue.

The ability of a reservoir to deliver oil into a well is described by a metric called the productivity index. As the name implies, it describes how productive a well could be, putting aside restrictions to flow through the well-riser system. The higher a reservoir's productivity index, the less effort is required to produce oil from the well. The productivity index is a function of several variables, including permeability, effective reservoir interval, skin (*i.e.*, near wellbore damage), and drainage volume and shape. It is standard practice to integrate the reservoir limits as part of flow calculations. This has not been done as part of the Government's flow estimates.

Data reviewed by BP's engineering and science team suggests that some of the assumptions the Government has used regarding reservoir properties are unrealistic. For example, at least one Government study estimated that the well had a productivity index of 50 bopd/psi and relied on that assumption to estimate the pressure difference between the reservoir and wellbore (*i.e.*, the drawdown). The Government's basis for using a productivity index of 50 appears to be undocumented in the study. Pressure measurements taken during the well integrity test are consistent with a higher drawdown because of the reservoir's skin. This skin is directly related to both reservoir inflow and wellbore friction, which demonstrates that other reservoir characteristics must be taken into consideration before an accurate flow estimate can be achieved. It is also not clear how the August 2 DOE/FRTG Estimate accounts for pressure loss due to friction in fluid flow up the well. Overall, a serious and comprehensive analysis of the flow rate over time must correctly account for factors such as these, and the review of available data suggests that the reservoir properties are more consistent with a lower daily flow rate during the duration of the flow.

5. The August 2 DOE/FRTG Estimate Is Inconsistent with the Observed Surface Expression

Significantly, the FRTG estimated the flow rate using surface expression as one of its primary methodologies in its May and June flow estimates, but surface expression was not considered in the August 2 DOE/FRTG Estimate. This is a significant flaw because the surface expression of the oil from the Macondo well on April 22, immediately following the sinking of the vessel, would not appear consistent with a flow rate of 62,000 bopd; rather the surface expression is far less than what would be expected for that flow rate. Additionally, in May, BP deployed a riser insertion tube tool ("RITT") that captured flow from the riser at a rate of approximately 8,000 bopd at certain points. Once the RITT was inserted and calibrated, the visible evidence of the oil plume and surface expression strongly suggested that the bulk of the flow was being captured. The FRTG recognized that the RITT was capturing the bulk of the flow coming from the riser, and this was one of the factors considered in the FRTG's lower-bound flow rate estimate of 11,000 bopd announced on May 27.

Despite this evidence, the August 2 DOE/FRTG Estimate suggests the flow rate was considerably higher, indicating that the total flow during the incident was between 53,000 and 62,000 bopd. This appears highly unlikely, and the failure to consider these issues is a significant failing in the August 2 DOE/FRTG Estimate. Moreover, the fact that there are a million barrels of oil in the Government's oil budget that are unaccounted for suggests the possibility that the Government has overestimated the volume of the discharge and that the "missing" one million barrels of oil never flowed from the well.

C. CONCERNS WITH OTHER FLOW RATE ESTIMATES

While the prior sections addressed concerns with the August 2 DOE/FRTG Estimate, BP also has similar concerns about a number of other flow rate estimates made during the course of the incident.

1. The June 14 estimate by the DOE science team

According to the October 6 Staff Draft, the DOE science team estimated a flow rate of approximately 60,000 bopd on June 13 based on pressure readings taken that day from a sensor in the Top Hat containment device above the BOP.[8/] BP has a number of serious concerns with this estimate. The Top Hat leaked and oil came out of the skirt (*i.e.*, the bottom) of the unit, making the pressure readings and flow behavior very difficult to model. Then, on one significant occasion, when the Enterprise collection vessel shut down, thereby pushing more flow out of the Top Hat, the measured pressure dropped when all expectations were that it should have risen. Difficulties with this methodology have been noted by the Government's scientists. Consequently, the evidence does not support the statement in the October 6 Staff Draft that "we now know" that the high-end estimate of flow rate on June 15 of 60,000 bopd was "accurate."

8/ October 6 Staff Draft at 14.

2. Professor Steven Wereley's estimate

On May 19, Steven Wereley presented a flow-rate estimate to the House Energy and Commerce Committee of 72,000 bopd on May 13, based on particle image velocimetry, a method using video of the plume emanating from the riser to determine flow velocity and inferring a flow rate from that velocity. Professor Wereley did not accurately model important aspects of hydrocarbon phase behavior. First, his estimate did not account for the fact that the flow was two-phase (45 percent gas on average, with separate plugs of gas and oil alternately coming out of the riser pipe). Second, his estimate was presented in volume-at-seabed conditions, where the liquid still contains dissolved gas and therefore occupies greater volume, rather than in industry-standard stock tank barrels (the units of the August 2 DOE/FRTG Estimate), which is the volume of that oil at atmospheric temperature and pressure. The reduction in volume is an effect commonly referred to as "oil shrinkage." In addition, Professor Wereley also did not know that the flow area was only 50 percent of what he expected, due to damage at the end of the riser. As a result, Professor Wereley's estimated flow volume is inflated by a significant amount. If Professor Wereley's estimate were to be corrected to account appropriately for these factors, the estimate would likely reflect a range of 15,000 to 20,000 bopd on May 13.

3. The Crone & Tolstoy estimate

BP has reviewed the study published by Timothy J. Crone and Maya Tolstoy in Science Express and has identified potential limitations in that analysis as well.[9/] In particular, the study uses inputs for the gas-to-oil ratio and for the gas solubility that BP believes to be significantly different from the actual properties of the fluids in the Macondo well. Problems with both inputs significantly inflated the calculated volume of flow and the flow rate. Appropriate inputs would have yielded flow rate estimates on the order of 40,000 bopd after riser cutting on June 3 rather than the 68,000 bopd posited by the authors. Further analysis of the study is required to ensure that BP fully understands the study's assumptions and methodology, and to determine whether the authors considered two-phase flow behavior in calculating their shear layer correction factor.

4. The Woods Hole estimate

Neither the October 6 Staff Draft nor the testimony of Woods Hole's Dr. Richard Camilli describes the manner in which the Woods Hole team developed its flow rate estimates. The team appears to have taken data from an ROV on May 31 and calculated a flow rate estimate of 59,000 bopd based on the flow rate of the total flux (oil plus gas) from the riser on that single day. However, the Woods Hole team does not appear to have considered oil shrinkage, *i.e.*, it did not reduce the volume of oil to stock tank conditions. This could have a significant impact, potentially reducing the estimated flow rate value by 30 to 35 percent.

9/ Timothy J. Crone and Maya Tolstoy, *Magnitude of the 2010 Gulf of Mexico*, Science Express, (Sept. 23, 2010).

D. MORE RELIABLE INFORMATION NEEDS TO BE OBTAINED TO GENERATE MORE ACCURATE ESTIMATES

BP believes that there is a significant amount of additional data and other information that needs to be collected and publicly released to facilitate an accurate estimate of flow rates. At present, these include the following (although more may be identified as the analysis proceeds): (i) The BOP, which is in the Government's possession, must be examined, analyzed, and measured. BP has not had access to the BOP since it was turned over to the Government and determining the position and condition of the rams and drill pipe within the BOP is a key component to a reliable estimate of flow rate over time; (ii) the riser kink, also in the Government's possession, must also be made available for examination. It is critically important to evaluate the erosion at the riser kink and the cross-sectional area of the riser, including the areas that were the subject of the velocimetry-based flow rate estimates. Precise measurement of the cross section is necessary because the flow rate is a function of the diameter of the pipe. Measurement of the pipe diameter will allow for a better understanding of the flow and considerable refinement of the velocimetry estimates; (iii) studies of the cement used in the well will provide a fuller understanding of the extent to which some of the cement remained in place and impeded the flow over time; (iv) it is also important to review the calibration and accuracy of the pressure gauges, also in the Government's possession, used to estimate the flow rate through the capping stack's kill line on July 14, upon which the Government's flow estimate was based, and to record the shut-in pressure (which leads to the estimate of the final reservoir pressure); (v) as discussed above, to evaluate the accuracy of the July 14 flow rate estimate, internal measurements can and should be made of the flow path geometry of the capping stack itself; and (vi) finally, reservoir core samples currently in the Government's possession should be analyzed as well. It is essential to marry the reservoir analysis with the flow rate analysis from other methods to derive a fully integrated estimate.

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BP appreciates the opportunity to set forth its current views on the accuracy of the existing flow rate estimates, even as Company engineers and scientists continue to work on the quantification issue. For all the reasons discussed above, BP believes the August 2 DOE/FRTG Estimate and purportedly similar estimates cited in the October 6 Staff Draft are fundamentally inaccurate and significantly overstate the total flow. As also stated above, additional work that takes into account all relevant factors affecting the flow rate is necessary to produce a more accurate and reliable flow rate estimate.

Now that the well is permanently sealed, and BP continues to work to meet its commitment to restoring the Gulf, it is imperative that we allow the experts investigating this issue to have both (i) access to all relevant data and information, and (ii) the time to analyze that data and information, to consult and collaborate with their colleagues in the scientific community, and to develop a well-founded, strongly defensible estimate of the flow rate. Once BP's technical team has access to the necessary data and information and has developed a flow estimate of its own, we will share it with the Commission. In the meantime, BP is concerned that the October 6 Staff Draft is based upon inaccurate assumptions and hypotheses about

matters that can be determined more accurately over time through more refined analysis and additional data collections. BP respectfully urges the Commission to acknowledge these uncertainties in current estimates and wait until the necessary data and information have been collected and properly analyzed before reaching any public conclusions on the issue of flow rate and volume.

BP welcomes the opportunity to meet with the Commission or its staff to discuss any of these issues and to answer any questions about its concerns.