Written Testimony for the Oil Spill Commission
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Thank you distinguished members of the Commission, fellow panel members, and Ladies and Gentlemen. Before joining the National Oceanic and Atmospheric Administration (NOAA), I worked as a Navigational Specialist at Jet Propulsion Laboratories. A common rocket science joke was that if you asked a team member when was dinnertime, you got an answer to 10 significant digits. Such precision was required if our spacecraft were to rendezvous with the correct celestial body. As an emergency responder for NOAA, I note that telling the on-scene command the nearest compass point for the expected direction for an oil slick trajectory is often sufficiently accurate to make the necessary operational decisions. Extra precision in such a case is irrelevant.

What are not acceptable in spill response are delayed forecasts. Predictions made after decisions are made are as useful as game score forecasts after the game has been played. The accuracy may be high in such circumstances but the utility is negligible.

FLOW RATE ESTIMATION

These points need to be considered in tracing the history of estimating the flow rate of the Deepwater Horizon oil spill at the Macondo well (also referred to as the MC 252 site). At the time of the oil spill, the initial assumption was that there was no leakage from the well and any oil threat would be from diesel spilled on the rig. By April 24th two remotely operated vehicles (ROV), which surveyed the well head and nearby pipelines, identified oil flowing from the broken riser pipe. Initial flow estimates were set at 1000 barrels per day (bbl/day).

Based upon the visual surface slick reports and a short video of the broken riser, NOAA suggested to the Unified Area Command (UAC) on April 26 that the flow rate was estimated at least 5000 bbl/day. This was an important action because with the increased spill size assessment, a much-expanded commitment was made to mobilize resources. On the advice of NOAA, NASA/USGS deployed the ER-2 aircraft equipped with the Airborne Visible InfraRed Imaging Spectrometer (AVIRIS), an advanced imaging tool. This system offered the potential to provide reliable surface oil volume estimation, something satellite imagery and normal aircraft observations could not.

The premise that the flow rate was higher than initial estimates was based not only on observations but planning estimates as well. Prior to drilling the MC 252 exploration well, a maximum uncontrolled discharge estimate of 162 thousand bbl/day was provided as part of the permitting process, although a credible worst-case scenario was considered to be much smaller.

Within the UAC, various approaches were being used to better estimate flow rate, even as the response proceeded. NOAA requested from BP improved video and started a search for multi-phase flow experts that could assess the oil flow from the riser, first within the agency and then at leading academic institutions. By May 12-13, NOAA had launched what became the Plume Team component of the Flow Rate Technical Group (FRTG), led by U.S. Geological Survey (USGS) Director, Dr. Marcia McNutt. On May 19, the National Incident Command (NIC) Interagency Solutions Group officially charted the FRTG. In addition to the Plume Team, another group within FRTG estimated the spill size by conducting a mass balance estimate and from it inferring a minimum lower bound for the flow rate. A third approach took calculations based on the amount of oil collected by the Riser Insertion Tube Tool (RITT), plus the estimate of how much oil is escaping the RITT, and added a term to account for leaking from the kink in the riser, a secondary leak source that appeared in early May. All of the FRTG sub-team findings were peer reviewed.

The Plume Team was tasked to estimate the flow rate from the broken riser at the source of the Deepwater Horizon spill, chiefly through quantitative visualization of the velocity of the exiting flow. The flow experts were:

Dr. Alberto Aliseda - Assistant Professor of Mechanical Engineering at the University of Washington. His research and teaching focuses on fluid mechanics with applications to Energy, Environmental and Biomedical Flows.

Dr. Oscar Flores - Research Associate in the Department of Mechanical Engineering at University of Washington. His primary area of research is fluid mechanics, with emphasis on wall-bounded turbulent flows and on density-stratified turbulent flows.

Dr. Juan C. Lasheras - Stanford S. and Beverly P. Penner Professor of Engineering and Applied Sciences Distinguished Professor of Mechanical and Aerospace Engineering and Bioengineering at University of California at San Diego. He is Chairman of the American Physical Society/Division of Fluid Dynamics. His research interests include turbulent flows, two-phase flows, and bio-medical fluid mechanics, and biomechanics.

Dr. Ira Leifer - Associate Researcher at the University of California at Santa Barbara. His research projects include a simulation of a subsurface oil spill by a hydrocarbon seep, and an estimate of the release points of oil slicks in the ocean using the natural laboratory of the Santa Barbara Channel.

Dr. James J. Riley - Paccar Professor of Engineering at the University of Washington and former Chairman of the American Physical Society/Division of Fluid Dynamics. He is a pioneer in the development and application of direct numerical simulation to transitioning and turbulent flows. His current research emphasizes turbulent, chemically-reacting flows, as well as waves and turbulence in density-stratified flows and rotating flows.

Dr. Omer Savas - Professor with the Department of Mechanical Engineering at the University of California at Berkeley. His research interests include fluid mechanics, aircraft wake vortices, biofluid mechanics, boundary layers, instrumentation, rotating flows, transient aerodynamics, turbulent flows, and vortex dynamics. His a fellow of the American Physical Society, an Associate Fellow of American Institute of Aeronautics and Astronautics, and A.D. Welliver Fellow of The Boeing Company

Franklin Shaffer - Senior Research Engineer with USDOE National Energy Technology Laboratory. For 25 years he has led the development of new high speed particle image velocimetry (PIV) tools to study particle flow dynamics of energy processes. He has received numerous national and international awards for development of new high speed imaging tools, including the R&D 100 Award and the Federal Laboratory Award for Excellence in Technology Transfer.

Dr. Steven Wereley - Professor of Mechanical Engineering at Purdue University. His research interests include biological flows at the cellular level, and electrical and optical manipulation of particles and fluids. He is on the editorial board of Microfluidics and Nanofluidics Journal and Experiments in Fluids and is an Associate Editor of ASME's Journal of Fluids Engineering.

In addition, the team received assistance from Dr. Paul Bommer, a Senior Lecturer in Petroleum Engineering at the University of Texas at Austin, who provided background on the Macondo reservoir and its expected behavior, Dr. Poojitha D. Yapa , a Professor of Civil and Environmental Engineering at Clarkson University who brought his considerable knowledge in modeling well blowouts, and Dr. Pedro Espina and Dr. Antonio Possolo of the National Institute of Standards and Technology who conducted uncertainty analysis on the team estimations.

Let me note, it is inspiring that the American people, at all levels, are willing to respond to the needs of their fellow citizenry. This spirit is exemplified by the fact that, when asked, these scientists were willing to give up weekends, holidays, and other commitments to help assist in this effort, in many cases without any guarantee of compensation.

The method employed by the Plume Team is a variant of particle image velocimetry (PIV). The term was first proposed in 1984 by R. J. Adrian, a reviewer of the team's effort. While difficult in practice, PIV is simple in principle. In this method a flow event, e.g. an eddy or other identifiable item, is observed in two consecutive video frames. Distance moved per time between frames gives a velocity, after adjustment for viewing angle and other factors. Repeated measurement over time and space give an estimated mean flow. Flow multiplied by cross-section area of the plume gives a volume flux.

Because the flow velocity is not uniform throughout the plume, multiple locations, known as interrogation spots, must be sampled to estimate an average velocity. Similarly, the cross-sectional area is time and spatially dependent as well as having diffuse boundaries so that an average cross-section, dependent upon the location of the interrogation spots, needs to be calculated. A further challenge for measuring the flow in this case is that it is not spatially or temporally uniform in mixture of gas and fluid.

For each of the interrogation sites a vector velocity is computed. The vector average of these velocities provides an average velocity. Combined with an average cross-section area, this yields a net flux of both gas and oil. A key parameter was this average ratio of gas to liquid. This term seemed to vary over the time period of the spill and during the time of the video clips. Increasing gas increased the velocity of the plume but decreased the mass flow. Analysis of the available short movies of the riser flow showed the existence of periods when the flow oscillates from pure gas to seemingly pure oil. These periods of gas-oil flow fluctuation are in the range of minutes. Longer periods may also exist but would require examination of longer clips to determine.

Another key question was the fluid velocity at the interior of the jet, something that obviously could not be directly observed. The different PIV experts approached this problem in different ways. Most assumed a correction factor for the interior velocity, usually two or two multiplied by the square root of two. One expert chose larger scale structure that he believed would respond to the interior flow directly so that no correction was necessary.

The Team at first had difficulty acquiring the high quality video necessary to use this methodology. All that they could conclude from the low quality imagery available was that the flow exceeded, by several times, the 5000 bbl/day estimate. At the request of the Team, BP engineers worked through the night on May 24 to find better video for the end of the riser in the only 36-hour window that met the team's requirements in terms of having no dispersants being applied, no RITT in the riser, and after the trench that contained the riser was excavated. Using the better quality video, the Team released an Interim Report on May 27[1], concluding that the <u>minimum</u> flow was at least 12,000 to 25,000 bbl/day, but that it could be significantly larger. This was subsequently revised on June 10 as a best estimate of 25,000 to 30,000 bbl/day but with the possibility that the flow could be as low as 20,000 or as high as 40,000.

By June 3, BP had severed the riser just above the Blow Out Preventer (BOP). The Team had requested, prior to the cut, that sufficiently high quality videos be taken of the flow immediately after the cut. On June 13, the Team met in Seattle to review this video, compare analysis of pre-riser videos and report their findings to Admiral

[1] http://www.deepwaterhorizonresponse.com/go/doc/2931/569235/

Allen. The Team conclusions are contained in a Plume Team Report of July 21, 2010 that has already been provided to the Commission.

A subsequent meeting was held in Washington DC on June 14 with representatives from the FRTG and the Department of Energy (DOE). This meeting produced the joint FRTG/DOE assessment that the flow rate was between 35,000 bbl/day and 60,000 bbl/day.

The DOE groups continued to refine their estimates, as did a group from Woods Hole Oceanographic Institute (WHOI), led by a fellow panelist. In late July, all the groups held teleconferences that generated the current best estimate of the flow rate as seen in Figure 1. The uncertainty on the flow estimates in this curve is approximately ±10 percent. A key measurement that refined the flow rates and raised the lower bound was the acquisition of an *in situ* hydrocarbon sample by the WHOI team that increased the oil to gas ratio that had been assumed by the Plume Team members.

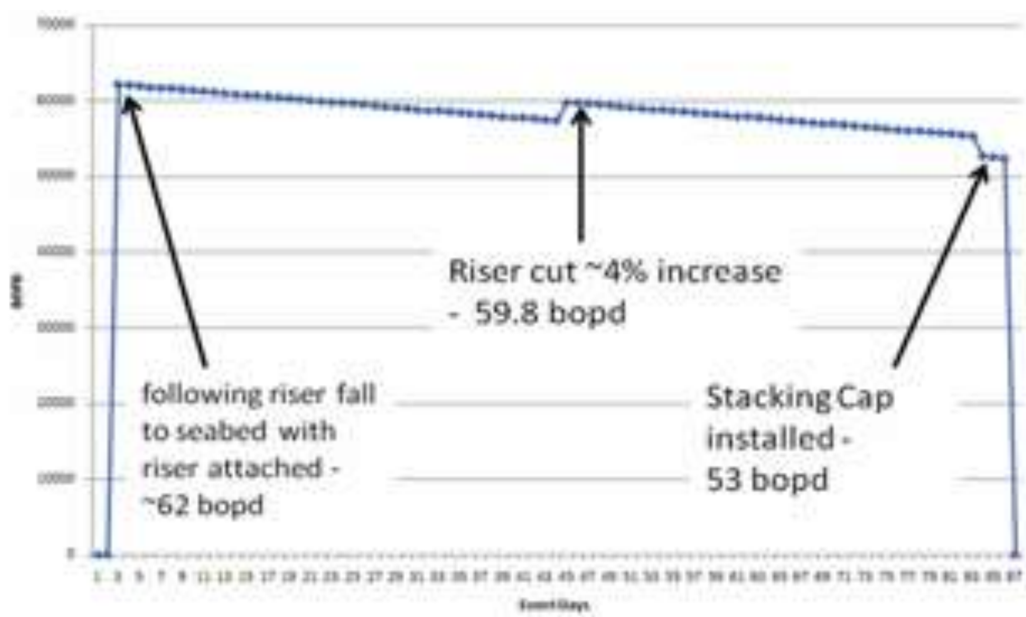

Figure 1 Flow rate estimate DOE/WHOI/FRTG

SHORT-TERM OIL FATE

Along with estimating the rate that oil was being released, an equal challenge for the response science team was to understand the immediate disposition of the oil. Once spilled into the marine environment and moved from the source, the oil interacts with the environment in a number of processes collectively called weathering. Short-term processes such as evaporation and dissolution change both the composition and properties of the oil, and can result in a smaller amount of oil in the marine environment.

The Oil Budget Calculator (calculator) was designed to assist the Situation Unit of the Incident Command System (ICS). ICS was developed to provide federal, state, and local governments, as well as private and not-for-profit entities, with a consistent framework for the preparation for, response to, and recovery from any incident or event, regardless of the size, nature, duration, location, scope, or complexity. The ICS Form 209 provides the mass balance information that the Incident Command needs to assess the size of the threat and make informed response decisions. Preparing the mass balance tables for an ICS 209 form is usually a simple, if slightly dull, process. For the typical tanker spill, vessel tanks are sounded, reports from the field estimate oil amount recovered or beached, and standard fate and behavior models, perhaps coupled with trained observer overflights, provide the remaining numbers for the tables. Such was not the case for the recent Deepwater Horizon oil spill. Instead, the most sophisticated technology, involving expertise and apparatus never before used on oil spills, was necessary to construct even the most rudimentary mass balance table. The Oil Budget Calculator was a combined effort of several federal agencies, leading academics in the field of spill science, and practical response experts with years of actual spill experience. Its results are a product of field measurement, scientific analysis and practical cleanup expertise. The emphasis was on getting a conservative answer so as not to underestimate cleanup requirements. In terms of response, this translates into using conservative estimates for cleanup efficiency, particularly with regard to skimmer efficiency and dispersant success.

It is important to remember that the Deepwater Horizon oil spill was an emergency, not an experiment. In spill emergencies, decision makers need immediate information that sometimes requires estimation when precise data are not available. Some oil fate processes are poorly understood and knowledge mostly consists of the personal experience of skilled spill responders. In developing the OBC, the team handled these poorly understood phenomena by constructing a consensus of the participating experts, or choosing a compromise value if consensus could not be reached.

The application of the tool defined its design requirements, which indicated that the calculator must:

- Be operable by response personnel, not specialized staff, and use easily accessible input data.
- Generate output that provides information similar to the standard ICS 209 form along with some estimate of the confidence of the answers generated.
- Be able to deal with incomplete, uncertain, or missing data and still provide the best estimate available to the Incident Commanders.
- Be conservative in its answers, i.e. it should err on overestimating oil that is still available to cleanup activities as opposed to oil that is not amenable to cleanup activities.

It is important to understand what the calculator was not designed to accomplish:

- The calculator is not a spill research tool, although new research has been a product of its development. Simplifications were made to make it accessible to response personnel.
- It is not a damage assessment tool nor should it be used in determining environmental impact of the spilled oil.
- It does not report the final fate of the spilled oil.

The usefulness and accuracy of the calculator needs to be assessed in the light of these requirements and restrictions. The answers that the calculator provides to the response only need to be accurate to the extent that they correctly inform cleanup decisions and do not lead to errors in response actions. Accuracy beyond that level, while desirable from a scientific viewpoint, is beyond the purpose for which the tool was designed. Hence, potentially large errors in, for example, dispersed oil estimates, were probably not of consequence unless it can be shown that response activities were misdirected as a result of that error.

As a response tool, the OBC became operational on June 22, 2010. Its methods are straightforward. However, it continues to undergo modification and refinement.

Dissolution and evaporation are computed from oil fate models calibrated to samples taken during the spill. Natural dispersion uses a modification of the normal algorithms to account for the fact that the turbulence causing droplet formation is not only breaking waves but also turbulent multi-phase flow out the riser. Chemical dispersion is based on expert estimates enlightened by lab studies and some field data. Burn values are based upon field reports, as are mechanical recovery numbers, with an adjustment for the fraction of recovered oil-water that is actually oil.

At first, the predictions of the OBC were only made available to officials within the command structure; spill professionals with many years experience and the background to understand the strengths and weaknesses of this tool. In keeping with the spirit of transparency for NIC procedures, it was decided to release to the public the results of the calculator in an effort to help the public gain a general understanding of the short-term fate of the oil. On August 4, Dr. Jane Lubchenco, Under Secretary of Commerce for Oceans and Atmosphere and Administrator of NOAA, presented at a White House press conference a NIC Report, entitled "What Happened to the Oil?" The NIC Report, using output from OBC, estimated that burning, skimming and direct recovery from the wellhead removed one quarter (25%) of the oil released from the wellhead. One quarter (25%) of the total oil naturally evaporated or dissolved, and just less than one quarter (24%) was dispersed (either naturally or as a result of operations) as microscopic droplets into Gulf waters.

This report was widely misinterpreted as claiming that three fourths of the oil was gone. Many people confused what was essentially a field summary from an emergency response tool with the typical formal research report. Alternatively, members of the team that generated the calculator, along with others, have submitted an abstract to the 2011 International Oil Spill Conference, assuming this to be the proper venue to present the formal scientific report, discuss the scientific challenges of doing a mass balance for this spill and assess the strengths and weaknesses of the calculator.

Because of the misunderstandings, we are expediting the preparation of a detailed technical document on the calculator, including extra background material for researchers new to the field. The formal document on the calculator is due out in mid-October.

The experience in developing the calculator points to the following areas of needed future research and planning related to mass balance emergency response questions:

(1) Protocols for surface sampling**:** Future response plans could specify methods for gathering water samples specifically for the purpose of assisting in estimating oil thickness and composition.

(2) Dispersed oil droplet size**:** A major improvement in estimating dispersant efficiency would be possible if practical operational tools and methods existed to characterize droplet size distribution of subsurface oil.

(3) Basic models for longer-term processes: While longer-term processes such as biodegradation often happen outside the time frames of the response, understanding and being able to predict such longer-term changes may be useful in making response decisions.

(4) Estimation of collected shoreline oil: For a complete mass balance, procedures should be implemented that estimate the fraction that is oil of oiled debris gathered from shoreline cleanup.

(5) Expanded modeling capabilities: Many of the team of scientists that assisted with the calculator are also part of a work group of spill experts developing the specifications for the next generation of oil spill model. These specifications need to be translated into real code.

NOAA continues to work with USGS and other organizations to improve our understanding of oil spill behavior.