FINAL

Peer Review Summary Report for the External Peer Review of

Quantitative Measurement of In-Situ Burn (ISB) Efficiency and Rate

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1. INTRODUCTION

EnDyna was tasked with managing the external peer review process to evaluate the draft final report of the BSEE study entitled, *Quantitative Measurement of In-Situ Burn (ISB) Efficiency and Rate*. The draft final report was prepared for the Bureau of Safety and Environmental Enforcement (BSEE) by Applied Research Associates, Inc., and the College of William and Mary, Virginia Institute of Marine Science, in August 2017.

The peer reviewer selection process involved selecting four scientific experts who were available to participate in the peer review, including preparing individual written peer review comments and attending a 2-day peer review panel meeting during a specific planned timeframe (December 4 through December 15, 2017). In recruiting these peer reviewers and managing the peer review, EnDyna evaluated the qualifications of peer reviewer candidates, conducted a thorough conflict of interest (COI) screening process, and independently selected the peer reviewers. EnDyna then provided management and oversight of the external peer review process, and produced this report that summarizes and synthesizes peer reviewer responses.

The sections below provide background on the BSEE study, describe EnDyna's process for selecting expert peer reviewers for the draft final report entitled, *Quantitative Measurement of In-Situ Burn (ISB) Efficiency and Rate* (BSEE study report), describe BSEE's objective and scope for this peer review, discuss the Supplemental Information and BSEE's written answers to peer reviewer questions, describe the peer review panel meeting, address the adequacy of information quality and independence of this peer review, and outline the organization of this report.

1.1 Background on BSEE Study

BSEE, within the U.S. Department of the Interior (DOI), is charged with the responsibility to permit, oversee, and enforce the laws and regulations associated with the development of energy (oil and natural gas) resources on the Outer Continental Shelf (OCS). BSEE's Oil Spill Preparedness Division (OSPD) is responsible for developing and administering regulations (30 CFR 254) that oversee the oil and gas industry's preparedness to contain, recover, and remove oil discharges from facilities operating seaward of the coastline.

During the oil spill response operations to the Deep Water Horizon (DWH) disaster, *in-situ* burn (ISB) operations were conducted from April 29, 2010 through July 19, 2010 where over 400 burns were responsible for removing approximately 220,000-310,000 barrels of oil from the marine environment.

ISB is an important tool used by spill responders to remove oil from the environment. During burn operations, it is important to know the volume reduction of oil for the overall accounting of the spilled oil (i.e., oil mass budget) and as a metric of success of various remediation methods (e.g., oil removed by ISB, oil treated by dispersants, oil removed by mechanical recovery). The volume of oil consumed is typically computed by performing a manual, coarse, time integration of the instantaneous burn area based on visual observations multiplied by an estimated burn rate. The burn rate (volume/time) is a number that depends on the type of oil, emulsification, estimated thickness, and size of the burn area. The area is typically estimated in the field using known boom geometry and visual inspection of the fire-water interface, and recorded using primarily pencil and paper. This manual process is extremely labor intensive and time consuming. In addition, each spill has a unique physical environment and set of oil properties—with both also affecting burn efficiency and burn rate. Thus, it is important to develop tools to quantify the efficiency and rate of burning in real time. In the lab, burn efficiency is determined by calculating the difference between the initial mass of oil and the mass of the residue divided by the initial mass of oil. While very effective in the lab, measurements of the initial and residual masses of oil in real spill environments are not feasible.

The success of ISB during the DWH response prompted BSEE to pursue research for potentially developing an automated method/technology to quantify the volumes and rates of oil being burned. BSEE awarded a contract in 2015 to fill this information need, which generated the draft final report entitled, *Quantitative Measurement of In-Situ Burn (ISB) Efficiency and Rate*. This report meets the criteria for "influential scientific information" under the Office of Management and Budget (OMB) Memorandum on Peer Review (OMB M-05-03). Therefore, BSEE determined that this report contains new scientific information and shall be subjected to peer review.

> A primary purpose for peer review at BSEE is to ensure that BSEE research products are based on sound science. Successful, defensible, and transparent peer review enhances the technical quality of BSEE research products.
>
> Another important reason why BSEE conducts peer review is to comply with federal requirements for information quality. Many of BSEE's research products are considered "influential" and are subject to OMB peer review requirements.
>
> ***BSEE Peer Review Process Manual***, p.3.

1.2 Identification and Selection of Expert Peer Reviewers

EnDyna was tasked with independently selecting three scientific experts who collectively had the background and proven experience for the following fields of expertise:

1) *In-situ* burning (ISB) in open water conditions,
2) Acoustic measurement, and
3) Photogrammetric measurement techniques.

EnDyna conducted an independent search for scientific experts in those three fields of expertise. The experts were identified through literature and internet searches of scientific journals, professional societies, universities, scientific meetings, nonprofit organizations, and governmental agencies. Both domestic and international affiliations were considered, as well as affiliations with industry, government, and academia. Specific examples of individuals and organizations contacted or used as a resource during the peer reviewer selection process include:

- National Oceanic and Atmospheric Administration (NOAA);
- National Aeronautics and Space Administration (NASA);
- U.S. Coast Guard (USCG), including the USCG Research and Development Center;
- U.S. Environmental Protection Agency (EPA);
- National Institute of Standards and Technology (NIST);
- California Department of Fish and Wildlife, Office of Spill Prevention and Response;
- Environment Canada;
- Nonprofit organizations (e.g., Woods Hole Oceanographic Institution);
- Private consulting firms (e.g., Spiltec, SL Ross Environmental Research Ltd., Ocean Imaging Corporation);
- Industry (e.g., Shell, Exxon, ConocoPhillips, Chevron);

- Universities (e.g., University of New Hampshire, Louisiana State University, University of Missouri-Columbia, Texas A&M University, University of Alaska-Fairbanks); and
- Individual consultants.

EnDyna contacted approximately 30 people, of which 14 candidates were interested in participating and available during the planned peer review panel meeting timeframe. The other candidates were either not available during the peer review timeframe, had COI or upcoming workload conflicts that led them to decline, or did not respond to our invitation. Interested candidates provided their name, contact information, and curriculum vitae (CV)/resume and/or biographical sketch containing their education, employment history, area(s) of expertise, research activities, recent service on advisory committees, publications, and awards.

1.2.1 Conflict of Interest Screening Process

EnDyna initiated COI screening on the 14 interested candidate reviewers to ensure that the experts had no COI or appearance of the lack of impartiality. The COI screening was conducted in accordance with the *BSEE Peer Review Process Manual* (dated August 2014) and involved each expert completing a COI questionnaire to determine if they were involved with any other work and/or organizations that might create a real or perceived COI for this peer review.

EnDyna received completed COI questionnaires from 13 of the 14 interested candidate reviewers. After reviewing the CV/resume for each interested candidate reviewer, EnDyna selected 11 experts as candidate reviewers who best met the required fields of expertise. After one of those 11 selected candidate reviewers disclosed COI issues before completing a COI questionnaire, EnDyna's pool of experts then included 10 candidate reviewers who best met the required fields of expertise.

EnDyna completed COI screening on the 10 candidate reviewers who best met the required fields of expertise. Although some candidates disclosed previous relationships with BSEE (i.e., consulting or peer review services), it was EnDyna's opinion that those relationships would not likely pose a real or apparent COI.

EnDyna recommended that BSEE consider adding a fourth peer reviewer to the panel if sufficient resources were available to expand the panel's expertise on *in-situ* burning in open water conditions. BSEE considered this recommendation, and provided the additional resources for a fourth peer reviewer. Expansion of the peer review panel to four expert peer reviewers allowed for selecting two peer reviewers with expertise on *in-situ* burning in open water conditions, which provided for two different scientific/technical perspectives for this requested area of expertise.

After the final peer reviewers were selected, the interested candidate that had disclosed COI issues before completing a COI questionnaire, eventually submitted a completed COI questionnaire that indicated this candidate (who had not been considered or selected) had a real COI and would have been excluded because of real COI.

A signed Non-Disclosure Agreement (NDA) was also collected from all of the candidate reviewers who best met the required fields of expertise.

1.2.2 Selection of Peer Reviewers

In selecting the peer reviewers, EnDyna evaluated each peer reviewer candidate's credentials to select the experts that, collectively, covered the areas of expertise needed for this peer review, had no real or apparent COI or appearance of the lack of impartiality, and were available to complete the peer review within the desired timeframe, including participation at a peer review panel meeting planned for between December 4 through December 15, 2017 in the Washington DC Metropolitan Area.

After review and consideration of the available information described above, EnDyna selected the following four expert peer reviewers: Dr. Oscar Garcia-Pineda, Dr. Bill Lehr, Mr. Neré Mabile, and Dr. Tom Weber. As noted under Section 1.2.1 above, the panel for this peer review was expanded to include four peer reviewers.

The four expert peer reviewers selected by EnDyna are provided in Table 1.1. These four peer reviewers were available to participate in the 2-day peer review panel meeting that was scheduled for December 11-12, 2017 at EnDyna's office in McLean, Virginia.

Table 1.1. Selected Peer Reviewers and Areas of Expertise

Dr. Oscar Garcia-Pineda, Director WaterMapping LLC Gulf Breeze, FL	• Photogrammetric measurement techniques
Dr. Bill Lehr, Senior Scientist Emergency Response Division Office of Response and Restoration National Ocean Service NOAA Seattle, WA	• *In-situ* burning in open water conditions (including DWH) • Photogrammetric measurement techniques
Mr. Neré Mabile, Integrity Management and Oil Spill Response Consultant Mabile Resources, Inc. Houston, TX	• *In-situ* burning in open water conditions (including DWH) • Acoustic measurement (ultrasonic techniques)
Dr. Tom Weber, Associate Professor Department of Mechanical Engineering; Center for Coastal and Ocean Mapping, College of Engineering and Physical Sciences University of New Hampshire Durham, NH	• Acoustic measurement

Table 1.2 provides an overview of the affiliations, advanced degrees, and selected publications for the four expert peer reviewers.

Table 1.2. Overview of Experience for Selected Peer Reviewers

Name	Affiliation / Advanced Degrees / Selected Publications
Dr. Oscar G. Garcia-Pineda	• Director, WaterMapping LLC, Gulf Breeze, FL (May 2014-present) • Visiting Researcher; Department of Earth, Ocean and Atmospheric Science; Florida State University (June 2009-present) • Ph.D., Coastal and Marine System Science, Texas A&M University Corpus Christi, 2009 • M.S., Geoscience, Instituto de Estudios Superiores de Tamaulipas, México, 2003 Selected publications: • Garcia-Pineda, O., I. MacDonald, C. Hu, J. Svejkovsky, M. Hess, D. Dukhovskoy, and S.L. Morey, "Detection of Floating Oil Anomalies from the Deepwater Horizon Oil Spill with Synthetic Aperture Radar," *Oceanography*, Vol. 26, No. 2, 2013. • Garcia-Pineda, O., I.R. MacDonald, X. Li, C.R. Jackson, and W.G. Pichel, "Oil Spill Mapping and Measurement in the Gulf of Mexico With Textural Classifier Neural Network Algorithm (TCNNA)," *IEEE Journal Of Selected Topics In Applied Earth Observations And Remote Sensing*, Vol.6, No. 6, 2013.
Dr. William J. Lehr	• Senior Scientist, Emergency Response Division, Office of Response and Restoration, National Ocean Service, National Oceanic and Atmospheric Administration (NOAA), Seattle, WA • Ph.D., Physics, Washington State University, 1976 • Project co-lead for Deepwater Horizon Oil Budget Calculator, produced by an Interagency task force to estimate and record mass balance of spilled oil and effectiveness of various response strategies, including *in-situ* burning • Project lead for ADIOS oil spill behavior program, which includes an *in-situ* module that calculates burn rate and hazardous smoke plume risk distance • Lead NOAA representative on NASA/NOAA/DOI project to map Deepwater Horizon surface oil using AVIRIS hyper-spectral system • Leifer, I., W.J. Lehr, D. Simecek-Beatty, et. al., "State of the Art Satellite and Airborne Marine Oil Spill Remote Sensing: Application to the BP Deepwater Horizon Oil Spill," *Remote Sensing of Environment*, Vol. 124, 2012.
Mr. Neré J. Mabile	• Integrity Management and Oil Spill Response Consultant, Mabile Resources, Inc. (2015-present) • Integrity Management Engineer, BP America (2007-2015), also Science and Technical Advisor for BP DWH Oil Spill Response *In-situ*-Controlled Burn Team • M.S., Environmental Quality Science, University of Alaska, Anchorage, AK, 1994 • B.S., Engineering Technology, Nicholls State University, Thibodaux, LA, 1973 • Mabile, N.J., "The Coming of Age of Controlled *In-Situ* Burning: Transition from Alternative Technology to a Conventional Offshore Spill Response Option," Interspill Conference 2012, London, England. • Allen, A.A., D. Jaeger, N. Mabile, and D. Costanza, "The Use of Controlled Burning during the Gulf of Mexico Deepwater Horizon (MC-252) Oil Spill Response." International Oil Spill Conference Proceedings, March 2011, Vol. 2011, No. 1.

Table 1.2. Overview of Experience for Selected Peer Reviewers

Name	Affiliation / Advanced Degrees / Selected Publications
Dr. Thomas C. Weber	• Associate Professor, Department of Mechanical Engineering; Center for Coastal and Ocean Mapping, College of Engineering and Physical Sciences, University of New Hampshire, Durham, NH (2017-present; Assistant Professor 2006-2017) • Ph.D., Acoustics, Pennsylvania State University, 2006 • M.S., Ocean Engineering, University of Rhode Island, 2000 • Weber, T.C., et. al., "Estimating Oil Concentration and Flow Rate with Calibrated Vessel-mounted Acoustic Echo Sounders," *Proceedings of the National Academy of Sciences*, Vol. 109, No. 50, December 11, 2012. • Loranger, S. [Dr. Weber's Ph.D. candidate student], C. Bassett, and T.C. Weber, "Measurements of the Acoustic Properties of Crude Oil," 5th Joint Meeting of Acoustical Society of America and Acoustical Society of Japan, Honolulu, HI, 2016.

1.3 Peer Review Objective and Scope

The objective of this external panel-style peer review was for BSEE to receive comments from individual experts on the draft final report entitled, *Quantitative Measurement of In-Situ Burn (ISB) Efficiency and Rate*. This panel-style peer review was technical in nature, reviewing the methods, data quality, the strengths of any inferences made, and the overall strengths and limitations of the study.

BSEE Charge for the Scope of this Peer Review

BSEE had carefully defined the scope of this peer review for the BSEE study report in order to focus the peer review process effectively on BSEE's Charge Questions. The peer reviewers were directed to keep their written peer review comments within the BSEE scope, which is defined below:

> **The scope of the peer review is focused on the methodology used in this study to determine burn volumes, burn rate, and burn efficiency. As such, the peer reviewers should focus on providing comments on the technical nature of the report. Because the review is technical in nature, the peer reviewers should not focus on editorial style.**

1.4 BSEE SME Consultation

The *BSEE Peer Review Process Manual* provides that BSEE may consult the research product authors or other BSEE subject matter experts (SMEs) in order to appropriately address peer review comments. The EnDyna Peer Review Lead coordinated with the BSEE COR, Ms. Karen Stone, to request additional technical and/or background information needed for this peer review. Prior to the panel meeting, the BSEE COR (Ms. Stone) consulted with the BSEE study report authors to provide:

1) Supplemental Information (see Section 1.4.1) requested by EnDyna's Peer Review Lead, and

2) BSEE's written answers to peer reviewer questions (see Section 1.4.2), which were compiled from the reviewer's initial written comments prior to the panel meeting by EnDyna's Peer

Review Lead; importantly, many of the reviewer's questions indicated that the draft final report entitled, *Quantitative Measurement of In-Situ Burn (ISB) Efficiency and Rate*, provided insufficient technical details to conduct an adequate peer review.

1.4.1 Supplemental Information

Prior to the peer review, EnDyna noted that the BSEE study report authors indicated at the top of page 22 in the draft final report that they did not provide details for how a polynomial fit to the speed of sound data was extrapolated to higher temperatures to determine the speed of sound at high temperatures during burning. Because EnDyna anticipated peer reviewers might need this technical detail for adequate review of the BSEE study report, EnDyna requested supplementary material from BSEE on that topic. EnDyna distributed this Supplemental Information to the peer reviewers, for review along with the BSEE study report.

1.4.2 BSEE's Written Answers to Peer Reviewer Questions

To facilitate obtaining as much technical information as possible prior to the panel meeting, EnDyna's Peer Review Lead analyzed each of the peer reviewer's initial written comments, and listed/paraphrased the peer reviewer's questions about the draft final report. EnDyna provided the BSEE COR (Ms. Stone) a list of the peer reviewer's questions in four batches, with the identity of each peer reviewer kept anonymous. EnDyna requested that BSEE provide answers to these peer reviewer questions in writing so that EnDyna could distribute written answers to all four peer reviewers in advance of the peer review panel meeting.

Section 7 (Appendix C) presents a compilation of BSEE's written answers to the peer reviewer questions re-organized by charge question and reformatted in a more readable manner. EnDyna distributed BSEE's written answers to the peer reviewer questions to all four reviewers on December 7, 2017 for review prior to the December 11-12, 2017 peer review panel meeting.

During the panel meeting, BSEE's written answers to the peer reviewer questions were used to clarify areas in the BSEE study report that had included insufficient technical details for adequate peer review. As documented in the final minutes from the peer review panel meeting provided in Section 6 (Appendix B); however, the peer reviewers found that some of BSEE's written answers to the peer reviewer questions also did not provide sufficient technical detail to conduct an adequate peer review.

In addition, BSEE will use the written answers to the peer reviewer questions in Section 7 (Appendix C) along with internal BSEE expertise in developing BSEE's responses to the external peer review comments provided in this peer review summary report.

1.5 Peer Review Panel Meeting

EnDyna selected a peer review panel of four senior scientists with expertise in: 1) *in-situ* burning in open water conditions, 2) acoustic measurement, and 3) photogrammetric measurement techniques.

Each peer reviewer prepared initial written comments on the draft final report entitled, *Quantitative Measurement of In-Situ Burn (ISB) Efficiency and Rate*, along with review of the Supplemental Information (see Section 1.4.1). The peer reviewers submitted their initial written comments to EnDyna prior to the December 11-12, 2017 peer review panel meeting. EnDyna compiled the peer reviewer's initial written comments and distributed those compiled initial written comments to all four peer reviewers on December 4, 2017 for review prior to the peer review panel meeting.

As discussed in Section 1.4.2, EnDyna also compiled BSEE's written answers to the peer reviewer questions re-organized by charge question and reformatted in a more readable manner (see Section 7 (Appendix C)). EnDyna distributed BSEE's written answers to the peer reviewer questions to all four peer reviewers on December 7, 2017 for review prior to the peer review panel meeting.

Each of the four peer reviewers confirmed that prior to the panel meeting they had reviewed EnDyna's agenda for the peer review panel meeting as well as EnDyna's compiled initial written comments on the BSEE study report from all four peer reviewers. Each of the four peer reviewers also confirmed they had reviewed BSEE's written answers to the peer reviewer questions prior to the panel meeting.

The peer review panel meeting was held on December 11-12, 2017 at EnDyna's office in McLean, Virginia. Section 6 (Appendix B) includes the final minutes and agenda for the panel meeting. EnDyna's agenda for the peer review panel meeting included "ground rules," which were based on the *BSEE Peer Review Process Manual* (dated August 2014). As outlined in the panel meeting agenda, the "ground rules" for the peer review panel meeting (see Section 6.1.2 in Section 6 (Appendix B)) were:

- An external peer review is intended to solicit individual reviewer feedback, to increase the independence of the review process.
- The panel is not asked to, and should not attempt to, form consensus or collective recommendations, ratings, or opinions, and panel reviewers must understand that they should provide individual feedback on the research product.
- Any BSEE staff that may attend the panel meeting can only provide background information on the research product to the peer reviewers, which can occur only during the panel meeting run by EnDyna, and at EnDyna's request.
- The panel meeting will not include discussion related to BSEE policy recommendations and decisions.

Because the four peer reviewers had different areas of expertise (see Table 1.1 in Section 1.2.2), some charge questions were more clear to one or more reviewers than to other reviewers. The discussion during the panel meeting helped elucidate additional technical/scientific information and perspectives from each of the reviewers based on their area(s) of expertise, providing useful technical/scientific background related to evaluating the quality of the technical/scientific information provided in the draft final report. In addition, the interaction among reviewers at the panel meeting helped clarify some technical complexities between the two subsections of the charge questions—measurement of slick thickness and measurement of slick area (see Section 2)—based on the reviewers' different areas of expertise.

The EnDyna Peer Review Lead, EnDyna's Facilitator, and all four peer reviewers agreed that the lively and amiable discussion exchanging technical/scientific information and perspectives related to the charge questions from the different areas of expertise among the reviewers at the panel meeting led to a more in-depth technical review for the peer reviewer's final written peer review comments.

The EnDyna Peer Review Lead developed draft minutes for the peer review panel meeting and distributed the draft minutes for review/comment to all four peer reviewers. After incorporating some clarifying comments from the peer reviewers, the EnDyna Peer Review Lead developed the final minutes of the peer review panel meeting (see Section 6 (Appendix B)).

After the panel meeting, each of the peer reviewers developed and submitted their final written peer review comments on the BSEE study report (see Section 5 (Appendix A)). EnDyna used the peer reviewer's final written peer review comments to develop this peer review summary report. The organization of this peer review summary report is outlined below in Section 1.8.

1.6 Adequacy of Information Quality for this Peer Review

During the second day of the peer review panel meeting, Mr. Rock, EnDyna's Facilitator, began the discussion of Charge Question 2.4 by noting that throughout the discussion of the charge questions about slick thickness (1.1–1.6) as well as the previously discussed charge questions about slick area (2.1–2.3) the common thread seemed that the peer reviewers understood the concept, but the draft final report lacked sufficient technical detail to evaluate this study's methodology.

Ms. Stone (BSEE COR) provided background information to clarify that BSEE is encouraging the research report authors—Applied Research Associates (ARA)—to pursue a patent application, which she explained is allowed in BSEE's research program. Because it was important to protect ARA's patent application, much of the technical details about this study's methodology were intentionally excluded from the draft final report as well as the Supplemental Information (see Section 1.4.1) provided for this peer review. Ms. Stone also explained that BSEE's written answers to the peer reviewer questions (see Section 7 (Appendix C)) were restricted to protect ARA's patent application.

The peer reviewers expressed concerns that protection of ARA's patent application led to insufficient technical details in the draft final report entitled, *Quantitative Measurement of In-Situ Burn (ISB) Efficiency and Rate*, provided by BSEE for this peer review. The peer reviewers agreed that the draft final report lacked sufficient technical detail to adequately evaluate information quality and to adequately review the methodology used in this BSEE study report to determine burn volumes, burn rate, and burn efficiency**.**

Subsequent to the peer review panel meeting, as discussed with the BSEE COR (Ms. Stone), the EnDyna Peer Review Lead communicated with the peer reviewers requesting that, for purposes of this peer review, the reviewers disregard the background information provided by Ms. Stone about ARA's patent application. The federal government conducts peer reviews for "influential scientific information" (see OMB's Information Quality Bulletin for Peer Review; OMB M-05-03). The *BSEE Peer Review Process Manual* (dated August 2014) is based on these OMB peer review requirements, which establish federal requirements for information quality for federal policy or regulatory decision-making.

1.7 Independence of this Peer Review

Federal agencies select an external peer review (contractor-managed peer review) to ensure independence from the Agency throughout the peer review process. As summarized in Section 1.5, the "ground rules" for the peer review panel meeting (also see peer review panel meeting agenda in

Section 6.1.2 in Section 6 (Appendix B)) included that each reviewer should provide individual feedback on the research report, which should be based on each reviewer's area(s) of expertise in developing the reviewer's final written responses to the charge questions.

During the afternoon of Day-2 of the peer review panel meeting, Ms. Stone (BSEE COR) mentioned several specific decisions she anticipated making (e.g., whether slick thickness is relevant, revising slick thickness method to use harmonic speed of sound, application of this methodology/technology for oil budget versus operational needs, approach for mapping techniques) for potential future revisions to this study's methodology. As noted in the final minutes for the peer review panel meeting, the Peer Review Lead reminded the reviewers at the end of the panel meeting as well as several times during discussions in the afternoon of Day-2 of the panel meeting that the peer review should focus on evaluating the draft final report, *Quantitative Measurement of In-Situ Burn (ISB) Efficiency and Rate*, and the technology proof of concept for the methods actually described in this BSEE study's draft final report, and not on providing advice to BSEE on detailed scoping for approaches for other potential future BSEE research projects.

Subsequent to the peer review panel meeting, as discussed with the BSEE COR (Ms. Stone), the EnDyna Peer Review Lead communicated with the peer reviewers requesting that the reviewers remember that the BSEE Charge for the Scope of this Peer Review (see Section 1.3) is focused on the methodology used in the BSEE study report to determine burn volumes, burn rate, and burn efficiency. The EnDyna Peer Review Lead emphasized that reviewers should base their final written comments for this peer review on the: 1) BSEE study report, 2) Supplemental Information (see Section 1.4.1), and 3) BSEE's written answers to the peer reviewer questions (see Section 1.4.2) that were provided before the panel meeting (see Section 7 (Appendix C)), and that the reviewers should disregard any specific decisions mentioned by the BSEE COR (Ms. Stone) at the peer review panel meeting about anticipated future revisions to this study's methodology.

1.8 Organization of Report

This peer review report is comprised of eight sections. ***Section 2*** provides the charge questions sent to each of the peer reviewers for comments, ***Section 3*** provides the synthesis of their peer review comments, and ***Section 4*** provides the peer review comments of each reviewer organized by charge question. ***Section 5*** (Appendix A) consists of the individual peer reviewers' comments. ***Section 6*** (Appendix B) provides the final minutes from the December 11-12, 2017 peer review panel meeting. ***Section 7*** (Appendix C) provides BSEE's written answers to the peer reviewer questions. The peer review materials packages in ***Section 8*** (Appendix D) are attached separately.

2. CHARGE QUESTIONS

The objective of this external panel-style peer review was to obtain written peer review comments from individual experts on the BSEE study report entitled, *Quantitative Measurement of In-Situ Burn (ISB) Efficiency and Rate*. Each peer reviewer was charged with evaluating the BSEE study report, providing their overall impressions of the scientific merit of this draft final report, and responding to 16 charge questions.

The 16 charge questions were divided into three sections, with the first section of charge questions focused on quantification of slick thickness, the second section focused on quantification of slick area, and the third section focused on the overall BSEE study report. The 16 charge questions provided to the peer reviewers are presented in Table 2.1 below.

The final minutes of the peer review panel meeting, presented in Section 6 (Appendix B), explain that the text "To demonstrate the technology proof of concept" was added to the beginning of Charge Questions 3.1–3.5. The purpose of amending those charge questions was to focus the peer reviewer's discussion at the peer review panel meeting as well as the peer reviewer's final written responses to those charge questions more effectively on how well the BSEE study report demonstrated the technology proof of concept for ISB in offshore open water conditions.

At the beginning of Day-1 of the peer review panel meeting discussions, Ms. Stone (BSEE COR) stated that evaluating the potential for using this study's methodology for ISB in open water conditions was out-of-scope. EnDyna's Peer Review Lead then noted that the BSEE COR (Ms. Stone) had specifically requested expertise with ISB in open water conditions for this peer review, instead of expertise with ISB in laboratory experiments. Moreover, during the peer reviewer selection process, BSEE had approved adding a fourth peer reviewer to the panel to expand the panel's expertise on ISB in open water conditions. Expansion of the peer review panel to four expert peer reviewers allowed for selecting two peer reviewers with expertise on ISB in open water conditions, which provided for two different scientific/technical perspectives for this requested area of expertise.[1]

As the peer review panel meeting proceeded, it became apparent that clarification was necessary regarding one of BSEE's requested areas of expertise—ISB in open water conditions—for this peer review. The amended Charge Questions 3.1–3.5 were intended to help clarify that:

- ISB in open water conditions should be considered in responding to the charge questions, as an area of expertise that BSEE specifically requested for this peer review; and
- The peer reviewers should evaluate the technology proof of concept, as described in the BSEE study report, based on this requested area of expertise—ISB in open water conditions—along with the other two requested areas of expertise: acoustic measurement and photogrammetric measurement techniques.

The four peer reviewers responded to these amended Charge Questions 3.1–3.5 during the discussion at the peer review panel meeting (see Section 6 (Appendix B)) and also responded to

[1] Mr. Mabile and Dr. Lehr were selected as peer reviewers because of their expertise with ISB in open water conditions.

these amended Charge Questions 3.1–3.5 for the peer reviewers' final written peer review comments (see Section 5 (Appendix A)).

Table 2.1. Charge Questions

1. Quantification of Slick Thickness:
1.1–Are the methods used to measure the oil slick thickness throughout the entire length of the *in-situ* burn tests valid? If yes, explain why these methods are valid. If not, how could the validity of the oil slick thickness measurement methods be improved or more clearly described?
1.2–Is the method to quantify the speed of sound in oil during *in-situ* burning operations valid? If yes, explain why the method is valid. If not, how could the validity of the speed of sound in oil quantification method be improved or more clearly described?
1.3–Does the report adequately address the measurement of varying slick thickness throughout the entire slick? If yes, explain why this measurement is adequately addressed. If not, how could these measurements be improved or more clearly described?
1.4–Does the report adequately address how the methodology for acoustic slick thickness measurements would be affected by waves and currents in open water conditions? Explain any issues or concerns that might affect the validity of this acoustical methodology in open water conditions.
1.5–Are the assumptions of the oil thickness algorithm input clearly defined and appropriate (see Sections 2.2.4, 3.1.3, and 3.2.3)? If yes, explain why. If not, explain how those assumptions could be defined more clearly. Provide a rationale for your answer about the appropriateness of the assumptions of the oil thickness algorithm input.
1.6–What are the strengths and weaknesses of the slick thickness determination methods? Provide a rationale for each identified strength or weakness.
2. Quantification of Slick Area:
2.1–Are the methods used to measure the surface area of the burning slick valid? If yes, explain why these methods are valid. If not, how could the validity of the area measurement methods be improved or more clearly described?
2.2–Are the numbers of images, heights, and angles from around the fire adequate for accurate area computations using the photogrammetric methods reported? Explain how the approach chosen could affect the validity of the methodology and results.
2.3–Does the report adequately address the methods to account for errors from obstructions and limited angles/heights/distances? Explain how the methods used to account for errors could affect the validity or scientific merit of the methodology and results.

Table 2.1. Charge Questions

2.4–Are the assumptions of the area algorithm input with respect to burning area of the slick clearly defined and appropriate (see Sections 2.1.1, 3.1.1, and 3.2.1)? If yes, explain why. If not, explain how those assumptions could be defined more clearly. Provide a rationale for your answer about the appropriateness of the assumptions of the area algorithm input with respect to burning area of the slick.
2.5–What are the strengths and weaknesses of the methods for the determination of the area(s) of the burning slick? Provide a rationale for each identified strength or weakness.
3. BSEE Study Report:
3.1–To demonstrate the technology proof of concept—Does the report adequately address the methodology to accurately calculate the volume of the entire slick given the differences in thicknesses throughout the entire slick being burned? Explain how this affects the validity or scientific merit of the methodology and results.
3.2–To demonstrate the technology proof of concept—Does the report describe with reasonable accuracy how burn volumes, burn rates, and burn efficiencies are computed? If yes, explain why these computations are described with reasonable accuracy. If not, how could the report describe these computations more clearly or with improved accuracy?
3.3–To demonstrate the technology proof of concept—Are the limitations and uncertainties clearly identified and adequately characterized for the determination of burn volumes, burn rates, and burn efficiencies? If yes, explain why. If not, how could the limitations and uncertainties for the determination of burn volumes, burn rates, and burn efficiencies be described more clearly or characterized with improved accuracy?
3.4–To demonstrate the technology proof of concept—What are the strengths or weaknesses of the methods used for the computations? Provide a rationale for each identified strength or weakness.
3.5–To demonstrate the technology proof of concept—Are there any other conclusions that could be drawn that are not adequately addressed in the report? Are there any other issues or concerns with the validity of the methodology or results that were not included in the previous charge questions?

3. SUMMARY OF PEER REVIEWER COMMENTS

This section provides a synthesis of the peer reviewers' comments, including general impressions (see Section 3.1) and responses to the charge questions (see Section 3.2). This synthesis was based on the individual peer reviewer's final written peer review comments (see Section 5 (Appendix A)) as well as the final minutes from the December 11-12, 2017 peer review panel meeting (see Section 6 (Appendix B)).

Throughout Section 3, each reviewer is represented by initials, typically placed at the end of text related to a reviewer's comments. The initials representing the four expert peer reviewers, as used throughout Section 3, are described below:

- OG represents Dr. Oscar Garcia-Pineda,
- BL represents Dr. Bill Lehr,
- NM represents Mr. Neré Mabile, and
- TW represents Dr. Tom Weber.

3.1 General Impressions

The reviewers provided varied comments as general impressions, in part based on their different areas of expertise (see Table 1.1 in Section 1.2.2). Overall, the four reviewers agreed that the draft final report lacked sufficient technical detail necessary for a full technical review of this study's methodology for measuring slick thickness and slick area to determine burn volumes, burn rate, and burn efficiency for ISB.[OG,BL,NM,TW] As an example of other issues identified with the draft final report, one reviewer emphasized there are some statements that are not self-evident and lack the literature references to support them. This reviewer also stated that several figures were not easily interpreted because those figures would require color-scales or contours (or both) in order to understand them.[TW] In providing general impressions, several reviewers focused on the validity of the technology proof of concept achieved by this study, as described in the draft final report.[BL,NM]

One reviewer commented that overall the research presented in the draft final report was "genuinely creative and innovative." The reviewer also commented that this research was "of high importance" as an opportunity to increase understanding of burn rates for ISB in controlled laboratory settings, especially to evaluate this method in cold weather environments (i.e., U.S. Army's Cold Regions Research and Engineering Laboratory (CRREL)).[OG] In contrast, two reviewers, based on expertise with ISB in offshore open water conditions, commented that burn rates for ISB are already well established through many previous research studies (see Section 3.1.1).[BL,NM]

The reviewer that commented this research was "of high importance" agreed with the soundness of the conclusions, because this reviewer believed that the results and importance of the laboratory ISB experiments justified the relevance of this research project. Although this reviewer commented that the information presented in the draft final report was objective and clearly described this study's experimental design and analytical methods, this reviewer also commented that the:

- Methodology for determining slick thickness lacked calibration accuracy (see Section 3.1.3),
- Draft final report lacked information on the repeatability of this study's experiments and verification of the laboratory ISB experiment (burn test) results (see Section 3.1.3),
- Slick area measurement method lacked calibration accuracy (see Section 3.1.5), and

- Draft final report did not provide adequate technical information on the algorithm used for image processing and the image geo-rectification technique used in the slick area measurement method (see Section 3.1.5).

Based on expertise in photogrammetric methods, this reviewer recommended that providing expanded technical information for each of those areas would improve the final report.[OG]

Another reviewer commented that overall the researchers had conducted a series of interesting laboratory ISB experiments using modern technology to improve on ISB, a traditional oil spill response tool. Based on expertise with ISB in offshore open water conditions, this reviewer stated that the acoustic impedance approach to measure slick thickness was particularly exciting and should have application well beyond ISB. Based on expertise in photogrammetric methods, this reviewer stated that measuring the surface area of the burning slick using visual and infrared cameras was more problematic and questioned whether the researcher's slick area measurement methods offered sufficient improvement for potentially applying this study's methodology during ISB operations in offshore open water conditions (see Section 3.1.6).[BL]

One reviewer commented that it was "truly exciting" that research was conducted to make progress on automated burn rate and burn efficiency data gathering for the purpose of calculating a more accurate burn volume of oil removed. This reviewer commented that overall some good laboratory ISB experiments were conducted to move technology forward to testing and validating automated fire area estimations, and this reviewer encouraged more research. The reviewer disagreed with the TRLs (Technology Readiness Levels) claimed by the researchers in the draft final report; instead, this reviewer concluded that a "partial simulation" was achieved through the laboratory ISB experiments. The reviewer recommended that technology deployment feasibility studies should focus on real world application in order to steer research direction toward the highest potential for success.

Based on expertise with ISB in offshore open water conditions, this reviewer identified several challenges for technology proof of concept for transitioning this technology from laboratory ISB experiments to ISB operations in offshore open water conditions. This reviewer noted that the draft final report concluded that the laboratory ISB experiments created the capability to measure the instantaneous burn rate and efficiency during ISB. The reviewer recommended that the researcher's conclusion should recognize that there are significant challenges remaining to implement this technology during ISB operations in offshore open water conditions (see Section 3.1.2 and Section 3.1.6). The reviewer emphasized that the researcher's conclusions in this study's final report should reflect that this technology's capability was tested in a controlled laboratory environment, with no waves, no emulsions, and with the total flexibility of placing cameras in ideal positions.[NM]

Another reviewer commented that the draft final report was well organized into sections that focus on the two basic measurement techniques, slick thickness and slick area, and on assessing these techniques in different scenarios (e.g., in the ice); however, the draft final report lacked sufficient technical detail to adequately describe the research conducted in this study. This reviewer commented that the idea behind this study was that it is of critical importance to measure the amount of oil removed by ISB, as well as to measure the efficiency of ISB (i.e., how much oil was burned compared to how much was left). Because ISBs can be dynamic, where ISB boom systems are towed to capture additional oil after ignition of the slick, the reviewer commented that knowledge of this dynamic burn rate is an important aspect of quantifying the amount of oil removed during ISB.

This reviewer commented that this study sought to improve on current methods for assessing ISB by measuring and monitoring the ignited slick area using infrared and/or visible cameras, and measuring the ignited slick thickness using upward-looking acoustic echo sounders. Based on expertise as an acoustic measurement SME, this reviewer stated that the overall methodology for determining slick thickness appeared flawed and summarized two key technical flaws (see Section 3.1.2). This reviewer described these two key technical flaws in more detail in responses to the charge questions (see Section 3.2.3 for Charge Question 3.1).[TW]

3.1.1 Burn Rates Already Measured through Previous Research Studies

One reviewer noted that the last paragraph on page 7 in the draft final report included the statement: "Specifically, at the start of this project the ability to directly measure the volume of burning did not exist." This reviewer emphasized that statement was inaccurate, because studies through NIST (Building and Fire Research Lab) and other commercial labs had previously researched dynamic, real-time volume calculations with burning different crude oils and had assessed slick thickness. The reviewer commented that the burn rate portion of this study was a re-examination of oil slick thickness while burning in pool fires, which was done many times before. The reviewer emphasized that there was even data from Russian field studies as far back as the 1950s.

Based on expertise with ISB in offshore open water conditions, this reviewer believed that there is already sufficient existing information about burn rates (or oil removal rates) with different crude oils and emulsified crude oils at varying thicknesses. This reviewer acknowledged; however, that the acoustic measurement approach had to be proven. The reviewer noted that this study re-confirmed existing information about burn rates through a different acoustic measurement approach using small pool fires. The reviewer commented that the burn rates provided in the draft final report correlated well with burn rates from many other studies.[NM]

As noted below (see Section 3.1.6), another reviewer stated that burn regression rates were already extensively measured and documented within a relatively narrow band for most oils.[BL] In addition, one reviewer noted that during the DWH ISB operations, already established burn rates for different burn types were used from previous laboratory measurements.[TW]

3.1.2 Slick Thickness Measurement Approach in Draft Final Report is Flawed

Based on expertise as an acoustic measurement SME, one reviewer stated that the overall methodology for determining slick thickness appeared flawed. This reviewer commented that one of these flaws was based on the premise that a measurement of slick thickness—or change in slick thickness over time—can be used to establish a burn rate. This reviewer acknowledged that such burn rates could be established for a static environment, such as the laboratory ISB experiments conducted for the draft final report.

This reviewer noted that during the panel meeting, ISB in offshore open water conditions was described as a dynamic burn, where vessels towed the ISB boom system (after ignition) to capture new oil to keep the burn going. The reviewer commented that a dynamic burn means that establishing a burn rate will require knowledge of how much is oil leaving the boomed slick (via burning, ignoring oil that might slip under the boom) and how much oil is entering the boomed slick during towing. The reviewer stated that the draft final report only presented results on oil slick thickness within the boom, and emphasized that this was not an adequate approach for determining a burn rate for ISB in offshore open water conditions (e.g., DWH ISB operations). The reviewer expressed concerns that this dynamic burn issue was not addressed in developing the methodology for determining slick thickness in the draft final report.

Based on expertise as an acoustic measurement SME, this reviewer stated that another technical flaw was related to the acoustic time-of-flight measurements and was also not addressed in the draft final report. The reviewer noted that measurement of slick thickness was inferred from a time-of-flight measurement of an acoustic pulse. The reviewer explained that converting time to thickness requires knowledge of the temperature profile in the burning slick. The reviewer also noted that the speed of sound in oil changes by a few m/s per degree Celsius change in temperature and that the temperature change from the ignited portion of the slick to the ocean water is several hundreds of degrees Celsius.

The reviewer commented that assuming that these temperature profiles are not constant throughout the ISB—and these temperature profiles did not appear constant during the measurements for this study's laboratory ISB experiments (burn tests)—converting the acoustic time-of-flight measurements would require measurements of the temperature profile of the slick. Measurement of the temperature profile of the slick would require knowing the location of both the top and bottom of the slick, and the reviewer stated that such knowledge would then obviate the need for the acoustic measurement in the first place.

This reviewer also stated there are additional methodology concerns associated with converting measurements of temperature to the speed of sound in an oil, which has undergone some unknown amount of weathering and/or emulsification.[TW]

Another reviewer commented that the significant challenge for technology proof of concept for this study's methodology will be to measure instantaneous burn rates with a realistic offshore ISB, much larger in size, with wave action, and varying oil/emulsion thicknesses contained within a towed ISB boom system. The reviewer acknowledged that the draft final report mentioned the lack of wave action and "current affects" in the laboratory ISB experiments. The reviewer emphasized that the technology proof of concept for transitioning acoustical measurement for slick thickness from laboratory ISB experiments to ISB operations in offshore open water conditions must include studies on acoustically measuring oil emulsion thicknesses.[NM]

3.1.3 Measurement of Slick Thickness Lacked Calibration Accuracy and Validity

Two reviewers commented that methodology for determining slick thickness lacked calibration accuracy.[OG,NM] One reviewer stated that the draft final report was unclear on the accuracy of the sound travel calibration through oil for the laboratory ISB experiments. The reviewer emphasized that draft final report did not adequately explain how calibration was handled through different temperature ranges with depth near the surface of the oil slick. Overall, throughout the draft final report, this reviewer found there was an absence of measuring equipment accuracy or margin of error notation.[NM] Another reviewer recommended that this study's final report should include expanded technical information about calibration of the slick thickness measurements with the acoustic system.[OG]

In addition, one reviewer expressed concerns about whether this study had included any repetition and verification of results for the techniques for slick thickness measurements with the acoustic system. Because the draft final report did not include the results for each of the 30 burn tests, this reviewer questioned whether the researchers had made any effort to compare burn times and burn rates over the same oil volumes. This reviewer commented that providing results about the repeatability of the laboratory ISB experiments would be valuable and would improve the understanding of the limitations and merits of the whole approach and reinforce understanding the validity of this study's methodology and results.[OG]

3.1.4 Measurement of Slick Thickness is Not Practical or Necessary

One reviewer commented that the laboratory ISB experiments involving acoustical measurement for slick thickness were interesting, but stated that the acoustic measurement method for slick thickness was not practical. Based on expertise with ISB in offshore open water conditions, this reviewer stated that applying real-time slick thickness measurement during ISB in offshore open water conditions is not practical and actually not necessary.

This reviewer emphasized that ISB in offshore open water conditions will involve emulsions most of the time, but the acoustic measurement method was tested only with fresh oil in the laboratory. As already noted above (see Section 3.1.1), this reviewer commented that the burn rate portion of this study was a re-examination of oil slick thickness while burning in pool fires, which was done many times before.

Based on expertise with ISB in offshore open water conditions, from an operations perspective, this reviewer would encourage research more focused on determining a "practical" way to obtain a <u>reliable average value</u> of the emulsified and varying slick thicknesses within a burning slick towed by an ISB boom system.[NM]

3.1.5 Slick Area Measurement Method is Feasible but Not Described Adequately

One reviewer, based on expertise in photogrammetric methods, recommended that this study's final report should provide expanded technical information on the algorithm used for image processing and the image geo-rectification technique used in this study's method to determine the surface area of the burning slick. This reviewer also recommended that this study's final report should include expanded technical information about calibration of the camera settings, because the draft final report did not provide any information on calibration accuracy for the slick area measurement method.[OG]

Another reviewer commented that measuring the slick area of an ignited portion of an oil slick during ISB using cameras seemed much more feasible than the researcher's proposed acoustic measurement method for determining slick thickness. This reviewer believed the slick area measurement method used in this study was more feasible, particularly given that the researcher's slick area measurement method is essentially the same approach used now for overflights of ISB operations in offshore open water conditions. This reviewer commented that replacing the subjectivity of human interpretation of slick area measurement with an automated method seemed a worthwhile endeavor.[TW]

3.1.6 Slick Area Measurement Method is Not Practical

Based on expertise in photogrammetric methods, one reviewer commented that the researcher's method to measure the surface area of the burning slick using visual and infrared cameras was more problematic than the researcher's acoustic measurement method for determining slick thickness. This reviewer questioned whether the slick area measurement methods used in this study offered sufficient improvement over traditional human eye methods to justify the increased complexity and likelihood of failure if used during ISB operations in offshore open water conditions.

Based on expertise with ISB in offshore open water conditions, this reviewer stated that burn regression rates have been extensively measured and already documented in a relatively narrow band for most oils. The reviewer commented that burn times can be measured with a stopwatch. Most burns are over 90% efficient, giving a reliable number at the end of the burn of how much oil was removed through ISB. The reviewer argued that this burn volume number generated by traditional means will be more accurate than other oil mass budget numbers, such as oil volume dispersed or evaporated, without going to the increased complexity of measuring the surface area of the burning slick though the methods researched in the draft final report.[BL]

As noted above, based on expertise with ISB in offshore open water conditions, from an operations perspective, one reviewer would encourage research more focused on determining a "practical" way to obtain a <u>reliable average value</u> of the emulsified and varying slick thicknesses within a burning slick towed by an ISB boom system. After accomplishing this, this reviewer would encourage designing a practical fire area monitoring/measuring method for deploying in a more typical environment for ISB operations in offshore open water conditions.

This reviewer argued that from an operations perspective, the largest margin of error is the fire area estimation, because of the challenge in maintaining a good quality sustained surveillance of the burning area of the slick. This reviewer would encourage more work focused on the application of photogrammetry and developing some realistic solutions to determine how to successfully implement automated fire area monitoring from feasible platforms. Based on expertise with ISB in offshore open water conditions, the reviewer emphasized that for burn volume estimation, the margin of error associated with the burn rate and slick thickness assumptions would be very small compared to estimating fire area on a constant, accurate, and consistent basis.[NM]

3.2 Responses to Charge Questions

The section below provides the synthesis of the four peer reviewers' comments, concerns, and suggestions regarding the charge questions.

3.2.1 Quantification of Slick Thickness Charge Questions

1. Quantification of Slick Thickness:
1.1–Are the methods used to measure the oil slick thickness throughout the entire length of the *in-situ* burn tests valid? If yes, explain why these methods are valid. If not, how could the validity of the oil slick thickness measurement methods be improved or more clearly described?
The reviewers varied in their responses about whether the methods used to measure oil slick thickness throughout the entire length of the ISB tests were valid. Three reviewers expressed various concerns about the validity of the oil slick thickness measurement methods,[OG,BL,TW] and one reviewer generally believed the methods were valid.[NM]

1. Quantification of Slick Thickness:

1.1–Are the methods used to measure the oil slick thickness throughout the entire length of the *in-situ* burn tests valid? If yes, explain why these methods are valid. If not, how could the validity of the oil slick thickness measurement methods be improved or more clearly described?

The three reviewer's various concerns about the validity of the oil slick thickness measurement methods are summarized in the following subsections, and also briefly listed below:

- One reviewer commented that the general "echo sounding" principle behind this study's experimental approach was valid, but noted this had already been reported in similar published work.[2] This reviewer identified several challenges raised by using this acoustic measurement method for ignited oil (e.g., significant temperature gradients and temperature variations throughout the burning oil) and also identified several obstacles to overcoming those challenges.[TW]
- Another reviewer commented that although the physics for this technique of using acoustic impedance to measure oil slick thickness seemed straightforward, it was unclear how this approach could calculate an accurate measurement of the significant temperature change through the burning oil, which was necessary to estimate slick thickness.[BL]
- One reviewer was not able to suggest a practical way to improve the laboratory ISB experiments, but expressed concerns that this study's experimental approach may not have included calibration tests to confirm the accuracy of the oil slick thickness measurements.[OG]

The reviewer that generally believed the slick thickness measurement methods described in the draft final report were valid, commented that a portion of the results from the laboratory ISB experiments confirmed a well-established oil thickness threshold for ISB to sustain combustion. This reviewer stated that data in section 2.2.4 of the draft final report showed that the burns in this study's laboratory ISB experiments stopped when the measured slick thickness reached 2mm. Based on expertise with ISB in offshore open water conditions, the reviewer commented that this 2mm oil thickness correlated very well with many previous laboratory tests. At this well-established 2mm oil thickness threshold, the water acts as a heat sink and starves the fire of the required heat to vaporize crude oil at the surface of the slick to sustain combustion.[NM]

One reviewer conducted some calculations based on Figure 12 in the draft final report. The reviewer understood that this technique of using acoustic impedance to measure oil slick thickness involved making a comparison between a sonic pulse signal reflection from the oil-air interface and a weaker reflection from the oil-water interface. The reviewer understood that slick thickness was calculated by multiplying the dual transit time through the oil by the signal velocity in the oil medium. Based upon Figure 12, the reviewer understood that the sonic pulse had a duration of approximately 2 microseconds. Using the equation on page 17 of the draft final report, this approximately 2 microsecond sonic pulse duration yielded the result that this study's method worked for a minimum measurable oil slick thickness of around 1 mm. This reviewer commented

[2] This reviewer referred to similar work conducted in "static" environments where the oil was not ignited (e.g., Bassett et al., JASA 137(1), EL32-EL38, 2015) that measured 40 mm thick layers of oil using broadband echo sounders operating between 200-300 kHz).

1. Quantification of Slick Thickness:
1.1–Are the methods used to measure the oil slick thickness throughout the entire length of the *in-situ* burn tests valid? If yes, explain why these methods are valid. If not, how could the validity of the oil slick thickness measurement methods be improved or more clearly described?

that this method's around 1mm minimum measureable oil slick thickness (per this reviewer's calculations) should be sufficient for ISB measurements, because an oil slick thinner than 2mm would not sustain a burn during ISB in offshore open water conditions.[BL]

Measurement of Temperature Gradient

One reviewer, based on expertise as an acoustic measurement SME, explained that measuring oil slick thickness requires the measurement of echoes from two interfaces—both the oil-air interface and oil-water (or flame-water) interface—and also requires estimating the harmonic mean sound speed in the oil. This reviewer commented that the general "echo sounding" principle behind this approach was valid, and stated that the draft final report showed clear evidence of resolvable echoes from both interfaces. This reviewer was not surprised this study's laboratory ISB experiments showed clear evidence of resolvable echos, given that similar results were already reported in recent publications.[3]

Although it was not clear in the draft final report, this reviewer had noted during the panel meeting that BSEE's written answers to the peer reviewer questions (see Section 7 (Appendix C)) clarified that this study did <u>not</u> use harmonic mean sound speed. This reviewer had explained during the panel meeting that it is necessary to measure temperature gradients in order to measure harmonic mean sound speed. The reviewer commented that because the sound speed gradient and the temperature gradient will be highly variable, the errors will be large with this acoustic measurement method.

This reviewer identified several challenges that must be overcome with respect using this acoustic method to measure slick thickness for an ignited or burning oil slick; however, and stated it was not clear how these challenges could be overcome.

This reviewer stated that the largest challenge with this acoustic measurement method for oil slick thickness was related to converting travel time to distance, which requires knowledge of the sound speed profile through the oil layer. This reviewer emphasized that the sound speed in oil is a strong function of the temperature gradient. The reviewer also had noted during the panel meeting that the sound speed in oil will vary for different types of oils.

The reviewer commented that the draft final report showed that the temperature of the burning oil varied by several hundreds of m/s over the temperature ranges relevant for burning oil (ocean temperatures to several hundred degrees Celsius). This reviewer emphasized that the temperature

[3] This reviewer referred to similar work conducted in "static" environments where the oil was not ignited (e.g., Bassett et al., JASA 137(1), EL32-EL38, 2015) that measured 40 mm thick layers of oil using broadband echo sounders operating between 200-300 kHz).

1. Quantification of Slick Thickness:

1.1–Are the methods used to measure the oil slick thickness throughout the entire length of the *in-situ* burn tests valid? If yes, explain why these methods are valid. If not, how could the validity of the oil slick thickness measurement methods be improved or more clearly described?

profiles in the draft final report showed strong gradients—of the order of 100 degrees Celsius per mm—with temperature variations occurring throughout the burning process.[TW]

Another reviewer commented that, according to the Supplemental Information (see Section 1.4.1) provided for this peer review, the oil temperature varied by several hundred degrees Celsius over the space of a few mm.[BL]

<u>Acoustic Travel Time Measurements: Harmonic Mean Sound Speed</u>

Again based on expertise as an acoustic measurement SME, one reviewer stated that the acoustic travel time measurements would require knowledge of the harmonic mean sound speed through the oil in order to estimate the oil slick thickness. This reviewer outlined several challenges:

- Knowledge of the harmonic mean sound speed requires a temperature profile, which in turn requires placement of temperature sensors in the oil slick,
- Those temperature sensors must be vertically referenced to the slick, and
- It is essential to know the location of the top of the slick.

This reviewer commented that knowing the location of the top of the slick seemed challenging given the results provided in the draft final report, which did not show a feasible approach to discriminating between the upper portion of the ignited oil slick and the flame above it. This reviewer commented that the draft final report suggested that the laboratory method had relied on a visual estimate for which of the temperature sensors were submerged, and included using a straight-line fit for the height (top) of the oil slick as it burned off. This reviewer emphasized that because the acoustic measurements did not match a straight-line fit, the temperature profiles used for this study represented only a crude estimate.

Overall, based on expertise as an acoustic measurement SME, this reviewer commented that the requirement for an accurate temperature profile would not be an easy challenge to overcome for making acoustic measurements of oil slick thickness during ISB, even in a laboratory setting.[TW]

Another reviewer commented that because the sound velocity through the oil depends on the spatially varying oil temperature, the use of this oil slick thickness measurement method may depend on the ability to accurately make measurements of this significant temperature change, or at least the ability to accurately estimate it for varying oil types and thicknesses. This reviewer emphasized that it was unfortunate that oil slick thickness was the exact unknown property to be calculated through this acoustic measurement method, given that estimates of the temperature gradient for different oil types and thicknesses may be a necessary input.[BL]

1. Quantification of Slick Thickness:

1.1–Are the methods used to measure the oil slick thickness throughout the entire length of the *in-situ* burn tests valid? If yes, explain why these methods are valid. If not, how could the validity of the oil slick thickness measurement methods be improved or more clearly described?

Interpretation of Figures 13, 14, and 15

With respect to the topic of converting travel time to distance, based on expertise as an acoustic measurement SME, one reviewer pointed out there was an important link in the draft final report between Figure 13 (acoustic result) and Figure 14 (temperature); however, this reviewer stated it was not clear whether these data were from the same laboratory ISB experiment. For background to explain this important link, the reviewer first noted that according to Figure 5, the acoustic sensor and the thermocouples were fixed with respect to one another, and the 16 thermocouples were located at fixed altitudes—with this reviewer emphasizing that the draft final report had erroneously described the 16 thermocouples located at fixed depths instead of altitudes.

Because Figure 14 in the draft final report indicated that the highest thermocouple was at the top of the oil slick prior to the burn, this reviewer assumed that if Figure 14 was correct, much of the temperature measurements during the laboratory ISB experiments were taken above the surface of the burning oil slick, presumably within the flame. The reviewer expressed concerns that the temperature measurements used to measure the oil slick thickness for the laboratory ISB tests were not all taken within the oil slick.

As further explanation, this reviewer commented that by approximately 200 seconds in Figure 14, about 7 mm of oil should have been burned according to Figure 19 and Figure 21. The reviewer concluded this suggested that the researcher's interpretation of Figure 15 was incorrect: the temperatures were partially from the air/flame (the top 4 mm of Figure 15-left, and four times greater than 175 seconds of Figure 15-right) and not all taken within the oil slick.[TW]

Another reviewer observed that the accuracy of the acoustic measurement method seemed to decrease as the temperature increased in the laboratory ISB experiments. This reviewer stated that Figure 13 showed that once serious burning commenced, the resolution of the thickness measurement diminished, with the transit time measurement spread over about 5 microseconds. This reviewer emphasized that the whole concept of an oil-water layer broke down after subsurface water boiling began in the laboratory ISB experiments. Based on expertise with ISB in offshore open water conditions, the reviewer acknowledged that subsurface water boiling would likely apply only to very shallow water circumstances, such as the ISB pan tests in the laboratory. Open ocean water should have sufficient convection to provide a necessary heat sink.[BL]

Emulsified Oil

In addition, based on expertise with ISB in offshore open water conditions, this reviewer commented that similar concerns may occur if this acoustic measurement method was applied to measure slick thickness for emulsified oil. The reviewer explained that as spilled oil becomes, or begins to become, emulsified, the heat from ISB will break down the emulsion and create local

1. Quantification of Slick Thickness:

1.1–Are the methods used to measure the oil slick thickness throughout the entire length of the *in-situ* burn tests valid? If yes, explain why these methods are valid. If not, how could the validity of the oil slick thickness measurement methods be improved or more clearly described?

turbulence. The reviewer emphasized that this may also interfere with the whole concept of an oil-water layer for this acoustic measurement method.[BL]

Based on expertise as an acoustic measurement SME, another reviewer had mentioned during the panel meeting that the speed of sound will be different in oil/water emulsions. For emulsions, this reviewer explained it would be necessary to measure the speed of sound for individual constituents and also to calculate them together.[TW]

<u>Graph in Supplemental Information</u>

One reviewer expressed concerns about "a somewhat perplexing graph" in the Supplemental Information (see Section 1.4.1) where the label was the speed of sound versus time but the equation applied to sound speed as a function of temperature (fitted as a cubic). The reviewer stated that details on this equation would have been useful to interpret the graphs provided in the Supplemental Information (see Section 1.4.1) for this peer review.[BL]

Calibration Tests

The reviewer that expressed concerns that this study's experimental method may not have included calibration tests for confirming the accuracy of oil slick thickness measurements did not see much information about calibration in the draft final report. This reviewer stated that the technical details about any calibration tests conducted should be included in this study's final report. The reviewer assumed that the acoustic measurement system used in the laboratory ISB experiments should have been tested under known variable oil slick thicknesses to validate that the acoustic system was calibrated. The reviewer commented that such calibration would be a control/monitoring test to validate that the oil slick thickness measurements made by the acoustic method during the laboratory ISB experiments were within range.

This reviewer also commented that this study's experimental method was designed to precisely monitor the sequence and gradient of the burning progression during ISB. The reviewer noted that although there are other options to measure oil slick thicknesses in those ranges (1-12mm), those other methods would be impractical because they would require interrupting burning to measure slick thickness. The reviewer suggested that burning could be interrupted to measure slick thickness perhaps for conducting calibration tests to determine the validity of slick thickness measurements made by the acoustic method.

In addition, this reviewer suggested that this study's final report should include a comparison of results from the different laboratory ISB experiments (series of burn tests made over a scale). To better understand the validity of the acoustic measurement methods used to determine oil slick thickness throughout the entire length of the ISB tests, this reviewer commented that through such

1. Quantification of Slick Thickness:
1.1–Are the methods used to measure the oil slick thickness throughout the entire length of the *in-situ* burn tests valid? If yes, explain why these methods are valid. If not, how could the validity of the oil slick thickness measurement methods be improved or more clearly described?
a comparison of the laboratory ISB experiment results, it would be expected that the burning times and ratios would be well correlated for ISB tests done under the same circumstances.[OG]

1. Quantification of Slick Thickness:
1.2–Is the method to quantify the speed of sound in oil during *in-situ* burning operations valid? If yes, explain why the method is valid. If not, how could the validity of the speed of sound in oil quantification method be improved or more clearly described?
One reviewer commented that the method to quantify the speed of sound in oil during ISB operations was adequate for this study's laboratory ISB experiments; however, this reviewer described concerns about limitations and uncertainties related to the high temperatures observed during the laboratory ISB experiments.[TW] Two reviewers were not sure if this method to quantify the speed of sound in oil during ISB operations was valid, and noted several concerns.[BL,NM] One reviewer was not aware of a more practical way to quantify the speed of sound in oil during ISB operations.[OG] One reviewer suggested that the researchers should include a reference in this study's final report for their statement made in the draft final report that: "the speed of sound in a fluid is directly related to the viscosity." This reviewer explained that sound speed is typically considered as related to the bulk modulus and the density of the fluid, and independent of the viscosity.[TW] **Significant Temperature Gradient** One reviewer, based on expertise as an acoustic measurement SME, stated that the method for quantifying the speed of sound in oil—making measurements of travel time over a fixed distance as a function of temperature—was adequate for use in the laboratory ISB experiments described in the draft final report. This reviewer emphasized that the range of temperatures over which the sound speed was measured was an important limitation; however, because this range did not extend to the high temperatures observed during the laboratory ISB experiments.[TW] One reviewer admitted insufficient acoustic measurement expertise to truly evaluate the method to quantify the speed of sound in oil during ISB operations, but observed no obvious scientific irregularities. This reviewer commented again (see Charge Question 1.1) that because the sound velocity through the oil depends on the spatially varying oil temperature, the use of this acoustic method seemed to depend on the ability to accurately make measurements of this significant temperature change, or at least the ability to accurately estimate it for varying oil types and thicknesses. This reviewer emphasized again that it was unfortunate that oil slick thickness was the exact unknown property to be calculated through this acoustic measurement method, given that estimates of the temperature gradient for different oil types and thicknesses may be a necessary

1. Quantification of Slick Thickness:

1.2–Is the method to quantify the speed of sound in oil during *in-situ* burning operations valid? If yes, explain why the method is valid. If not, how could the validity of the speed of sound in oil quantification method be improved or more clearly described?

input.[BL]

Another reviewer commented that the variable temperature gradient throughout the slick thickness under the fire during ISB would make it difficult to accomplish accurate calibration for this acoustic measurement method to quantify the speed of sound in oil during ISB operations. Because the calibration and accuracy of the acoustic measurement instruments used in quantifying the speed of sound during the laboratory ISB experiments was not discussed in the draft final report, this reviewer was not sure the calibration for this acoustic method was accurate, and thus was not sure how to evaluate the validity of this study's method to quantify the speed of sound in oil during ISB operations.[NM]

Equations

Based on expertise as an acoustic measurement SME, one reviewer noted that a polynomial fit was employed to extrapolate the speed of sound to higher temperatures, but the uncertainty of this polynomial fit was not established and presumably some unknown bias was retained in the final acoustic measurement method results for oil slick thickness.[TW]

Another reviewer observed that, according to the Supplemental Information (see Section 1.4.1), the researchers used visual inspection to determine thermocouple location relative to the top of the slick. The reviewer emphasized that would not be a valid approach for ISB in offshore open water conditions. The reviewer acknowledged that the Supplemental Information (see Section 1.4.1) indicated, in the future, that the researchers would determine the location of the top of the slick, in relation to the thermocouples, using a non-linear function of time. Because this reviewer could not see how using nonlinear functions would solve the problem, the reviewer suggested that an explanation was needed in this study's final report.[BL]

Dynamics of Oil-Water Interface

One reviewer stated during the panel meeting that at some point during ISB operations, the oil-water interface will become very complicated and it will become a very dynamic (rough) interface. Based on expertise as an acoustic measurement SME, this reviewer stated that the draft final report seemed to include "a lot of averaging" for the acoustic measurement for the laboratory ISB experiments because the oil-water interface shown in the draft final report was smooth. This reviewer commented that there was actually significant variability in the acoustic data/results from the laboratory ISB experiments and expressed concerns that this significant variability was not explained in the draft final report.[TW]

1. Quantification of Slick Thickness:
1.3–Does the report adequately address the measurement of varying slick thickness throughout the entire slick? If yes, explain why this measurement is adequately addressed. If not, how could these measurements be improved or more clearly described?

Two reviewers stated that the researchers did not actually attempt to measure varying oil slick thickness throughout the entire slick in the laboratory ISB experiments.[BL,TW] Two reviewers commented that the laboratory ISB experiments adequately addressed the measurement of varying oil slick thickness throughout the entire slick.[OG,NM]

One reviewer commented that, as a general rule, reports for projects of this nature will provide extensive tables of measurement results or, at a minimum, error bars on the graphs such as Figure 19 in the draft final report. This reviewer expressed concerns that both tables of measurement results and error bars on the graphs were lacking in the draft final report.[BL]

Laboratory ISB Experimental Approach did Not Measure Varying Slick Thicknesses throughout Entire Slick

One reviewer pointed to page 53 of the draft final report where the researchers stated: "For this project, we did not attempt to measure the spatial variations of the slick thickness." Based on expertise with ISB in offshore open water conditions, this reviewer commented that actually not including measurement of varying slick thickness was unfortunate because one of the most attractive features of this experimental approach could have been the capability to measure surface oil thickness at various locations. This reviewer noted that a practical tool operationally deployed during an actual oil spill incident could, along with modern remote sensing techniques, finally provide what this reviewer described as the "holy grail" of spill science, a trustworthy estimate of surface oil volume.[BL]

Another reviewer, based on expertise as an acoustic measurement SME, concluded that the draft final report actually did not address the measurement of varying slick thickness throughout the entire slick. This reviewer observed that only measurements from one transducer per laboratory ISB experiment (burn test) were described in the draft final report. The reviewer noted that the draft final report illustrated the use of up to eight (8) acoustic transducers in the laboratory ISB experiments (Figure 5), but any results of measurements from these multiple transducers were not included in the draft final report.

This reviewer found only one exception during the in-ice burn tests, which described measurements from a single frame-mounted and a single remote operated vehicle (ROV) mounted transducer, but also found that subsequently in the draft final report (page 53), the researchers stated: "For this project, we did not attempt to measure the spatial variations of the slick thickness."

This reviewer commented that given the constrained laboratory setting of the laboratory ISB experiments, it was not clear that the slick thickness should even vary during the burn tests. The reviewer argued that it would still be valuable to explore the variations in the slick thickness measurements between the different sensors, with some attempt to partition the inevitable

1. Quantification of Slick Thickness:

1.3–Does the report adequately address the measurement of varying slick thickness throughout the entire slick? If yes, explain why this measurement is adequately addressed. If not, how could these measurements be improved or more clearly described?

differences between actual changes in slick thickness and measurement uncertainty/bias.[TW]

Another reviewer pointed to page 23 of the draft final report where the researchers stated that the calculations for the laboratory ISB experiments "assumed the thickness was constant over the entire surface of the burning slick," and acknowledged that although not addressed by the laboratory ISB experiments, the draft final report mentioned and recognized the fact that oil slick thickness will vary for larger burns:

> "For direct comparison Figure 21 shows the thickness measured directly from the acoustic measurements and the thickness derived from the weight, area of the burn container, and the temperature dependent density of the oil. For these calculations we assumed the thickness was constant over the entire surface of the burning slick. For the small scale burns in this study, this assumption is reasonable. However, in larger burns this assumption is not likely to be valid and the spatial variations of the thickness will need to be measured to accurately determine the volume of oil."
> (page 23 of draft final report)

Nevertheless, as discussed in the subsection below, this reviewer believed that the laboratory ISB experiments adequately addressed the measurement of varying slick thickness throughout the entire oil slick.[NM]

Laboratory ISB Experimental Approach Adequately Addressed Slick Thickness

One reviewer stated that for the small burns for the laboratory ISB experiments the draft final report adequately addressed varying oil slick thickness throughout the entire slick. This reviewer suggested that to improve these measurements; however, thicker oil slicks must be studied and measured. As noted in the subsection above, this reviewer pointed to page 23 of the draft final report where the researchers recognized that slick thickness will vary for larger burns.[NM]

Another reviewer stated that the draft final report adequately addressed the measurement of varying oil slick thickness throughout the entire slick The reviewer commented that the spatial distribution of the transducers was explained graphically in the draft final report. This reviewer stated that if there were any variances in the slick thickness inside the tank during the laboratory ISB experiments, then the transducers located in different places would record that variance.[OG]

Technology Proof of Concept for ISB in Offshore Open Water Conditions

The reviewer that suggested research on thicker slicks explained that the need to study and measure thicker slicks is related to technology proof of concept for transitioning this slick thickness measurement method to ISB in offshore open water conditions. The reviewer described ISB in offshore open water conditions, based on actual DWH ISB Team operations. This reviewer

1. Quantification of Slick Thickness:
1.3–Does the report adequately address the measurement of varying slick thickness throughout the entire slick? If yes, explain why this measurement is adequately addressed. If not, how could these measurements be improved or more clearly described?
explained that an ISB boom system will create slicks up to 16” to 18” in depth right near the apex of the “U” shaped boom. Pulling an ISB boom system at ½ to ¾ knot, will build up oil to a depth reaching the bottom of the boom skirt. The slick will vary in depth with a slight thickening at the leading edge of the ISB boom system with increasing thickness towards the apex. This dynamic slick thickness variation inside of an ISB boom system will depend on the type of oil, viscosity, gravity, speed of tow, fluid dynamics, drag coefficients, etc.[NM] Another reviewer commented on considerations related to technology proof of concept for transitioning this slick thickness measurement method to ISB in offshore open water conditions. This reviewer explained that thick oil collected in ISB boom systems that have an open end to the sea will show some small slope from front to back. The reviewer would be surprised if that small inclination interfered with local thickness measurements by this approach if sufficient acoustic sensors with adequate focus (or a moving sensor with several measurements) were used to calculate the slope. The reviewer suggested that more problems might arise because of spatially varying oil input to an open-ended burn area within an ISB boom system, causing some cross-sectional thickness differences at the mouth of the opening. During the final burn stages, certain areas within the ISB boom system will stop burning before other areas but by then ISB will have consumed most of the oil. This reviewer noted that the draft final report did not discuss unburned residue from the laboratory ISB experiments, and did not address how unburned residue could affect slick thickness and slick area measurements. The reviewer also noted that the draft final report did not discuss the degree of uncertainty expected from variations in water depth of the ROV, a length scale larger than the oil slick thickness. This reviewer believed that presumably the acoustic system could automatically correct for this by the timing of the return signal from the oil-water interface; however, because this was unclear the reviewer suggested that this study’s final report should provide the relevant details.[BL]

1. Quantification of Slick Thickness:
1.4–Does the report adequately address how the methodology for acoustic slick thickness measurements would be affected by waves and currents in open water conditions? Explain any issues or concerns that might affect the validity of this acoustical methodology in open water conditions.
Three reviewers stated that the draft final report did <u>not</u> address how the methodology for acoustic slick thickness measurements would be affected by waves and currents.[BL,NM,TW] All four reviewers commented on various issues that could impact the validity of this acoustic slick thickness measurement methodology in open water conditions.[OG,BL,NM,TW] Two reviewers commented on the proposed approach to operate an ROV as part of making acoustic slick thickness measurements in open water conditions.[OG,TW] Two reviewers provided information and references from previous

1. Quantification of Slick Thickness:

1.4–Does the report adequately address how the methodology for acoustic slick thickness measurements would be affected by waves and currents in open water conditions? Explain any issues or concerns that might affect the validity of this acoustical methodology in open water conditions.

laboratory testing.[BL,NM]

Validity of Acoustic Method in Open Water Conditions

One reviewer stated that the draft final report did not address how the methodology for acoustic slick thickness measurements would be affected by waves and currents as used in the researcher's other laboratory ISB experiments (e.g., using ROV), which the researchers had described specifically on page 53 of the draft final report:

> "In open water deployments, the waves and currents will be an issue that was not experienced in this deployment at CRREL. As part of a separate project we are working on deploying the acoustic slick thickness measurements on ROV and autonomous underwater vehicles and have achieved accurate measurements of the slick thickness in various sea states ranging from harbor chop to ~23 inches in height." (page 53 of draft final report)

This reviewer stated that the validity of this acoustic slick thickness measurement method in open water conditions might be affected by the presence of emulsions, which would be created by waves, because emulsions would affect oil slick density, thus affecting the acoustic system calibration and the acoustic measurement of slick thickness. This reviewer also explained that the level of emulsification would vary throughout the oil slick during ISB in offshore open water conditions.[NM]

Another reviewer also stated that the draft final report did not address how the methodology for acoustic slick thickness measurements would be affected by waves and currents. Based on expertise as an acoustic measurement SME, this reviewer explained that waves and currents could potentially create emulsions of oil and water, or gas bubbles, which could lead to increased volume reverberations below the slick, and confound the detection of the two interfaces and thus make acoustic slick thickness measurement unreliable. The reviewer emphasized that the methodology for detecting the two interfaces (oil-air and oil-water) relied on identifying the same cycle of the reflected waves for the two different interfaces, and explained that volume reverberations could make such detection unreliable. This reviewer suggested that other approaches that rely on match filtering and/or the signal amplitude envelope may be a more robust methodology for acoustic slick thickness measurements, because waves and currents during ISB in offshore open water conditions that create emulsions of oil and water would make it difficult to measure the two interfaces (oil-air and oil-water).[TW]

Another reviewer questioned whether this study addressed how the methodology for acoustic slick thickness measurements would be affected by waves and currents because no details were provided in the draft final report. This reviewer commented that the acoustic slick thickness

1. Quantification of Slick Thickness:

1.4–Does the report adequately address how the methodology for acoustic slick thickness measurements would be affected by waves and currents in open water conditions? Explain any issues or concerns that might affect the validity of this acoustical methodology in open water conditions.

measurement method generally seemed scientifically sound for non-burning oil under calm surface conditions. The reviewer stated that comparison with direct oil mass measurements (Figure 22) supported this conclusion. The reviewer observed that the researchers asserted on page 17 of the draft final report that the calculations for the acoustic measurements of slick thickness compared wave peak measurements when waves were present; however, the reviewer expressed concerns that details on how this was achieved were missing from the draft final report. This reviewer again commented that, as a general rule, reports for projects of this nature will provide extensive tables of measurement results or, at minimum, error bars on the graphs, and expressed concerns that both tables of measurement results and error bars on the graphs were lacking in the draft final report.

This reviewer suggested that the validity of this acoustic slick thickness measurement method in open water conditions might be affected by whether oscillating interfaces of different frequencies from waves and currents on the water surface would increase spatial return signal scatter. The reviewer commented that constant currents should not be a problem for this acoustic measurement method because such currents will, by necessity, be less than a knot for the ISB boom system to contain the spilled oil. During ISB in offshore open water conditions, varying currents may cause problems in maintaining a cohesive slick and controlling the burning oil within an ISB boom system. During DWH ISB operations, burning oil often escaped from the ISB boom systems.[BL]

Another reviewer commented that the validity of this acoustic slick thickness measurement method in open water conditions might be affected by lack of acoustic precision, which is dependent on the alignment between the transducer and the surface. The reviewer explained that if turbulence (waves or currents) were present, this turbulence might compromise the accuracy of the readings since the transducer would no longer be perpendicular to the surface where oil is floating. This reviewer emphasized that the oil layer dynamics will be changing its thickness constantly and might not be captured properly by the sensor.[OG]

ROV Operation

Two reviewers expressed concerns about ROV operation for making acoustic slick thickness measurements in open water conditions.[OG,TW] One reviewer stated that waves and currents could hinder the safe operation of placing an ROV underneath the surface of burning oil.[TW] Another reviewer questioned the ability to operate the free swimming ROV from a vessel. This reviewer noted that the draft final report mentioned testing the acoustic slick thickness measurements within a range of sea state conditions (harbor chop to ~23 inches wave height). This reviewer suggested that the researchers should provide more awareness about the limitations of the acoustic system. Based on expertise in mapping oil spills, this reviewer argued that the ability to operate an ROV system similar to the ROV shown in the draft final report (Figures 55, 56, and 57) would be extremely challenging beyond a strict range of sea state conditions. The reviewer commented that

1. Quantification of Slick Thickness:
1.4–Does the report adequately address how the methodology for acoustic slick thickness measurements would be affected by waves and currents in open water conditions? Explain any issues or concerns that might affect the validity of this acoustical methodology in open water conditions.
the technical details about how the researchers investigated the free swimming ROV at CRREL were very limited in the draft final report.[OG] **References from Previous Studies** One reviewer noted that the draft final report on page 53 mentioned other studies where slick thickness measurements were successful for wave heights of ~60 cm, greater than the freeboard of many ISB boom systems used to contain the oil. BSEE's written answers to the peer reviewer questions (see Section 7 (Appendix C)) provided references for those other studies. Although the reviewer was not tasked to evaluate the reports for those other studies, the reviewer had conducted a cursory analysis indicating that those earlier studies included more measurement data results than this draft final report.[BL] Another reviewer provided information and references from previous laboratory testing, specifically: • Tam and Purves (1980) conducted prior testing of small waves (5 and 10cm), and found the presence of waves reduced the burning rates by increasing the heat transfer to the underlying water. Reference: Tam, W.K. and W.F. Purves. 1980. Experimental evaluation of oil spill combustion promoters. Proceedings of the Oceans '80 International Forum on Ocean Engineering in the 80s. IEEE, Piscataway, NJ, pp. 415-422. • Buist and McAllister (1981) reported reduced burn times at constant tow speeds with increasing regular wave heights, but no decrease in visible combustion intensity. The latter test was done at the Ohmsett test facility. Buist and McAllister (1981) also noted that the effects of currents on ISB burning rates were negligible. Reference: Buist, I.A. and I.R. McAllister. 1981. Dome Petroleum's fireproof boom–development and testing to date. Proceedings of the Fourth Arctic and Marine Oil Spill Program Technical Seminar, June 16-18, Edmonton, Alberta. Environment Canada, Ottawa, Ontario, pp. 479-497.[NM]

1. Quantification of Slick Thickness:
1.5–Are the assumptions of the oil thickness algorithm input clearly defined and appropriate (see Sections 2.2.4, 3.1.3, and 3.2.3)? If yes, explain why. If not, explain how those assumptions could be defined more clearly. Provide a rationale for your answer about the appropriateness of the assumptions of the oil thickness algorithm input.
Two reviewers indicated that the oil thickness algorithm seemed appropriate, but stated that evaluating the oil thickness algorithm assumptions was difficult given the limited information in the draft final report. The specific concerns of those two reviewers are summarized below.[BL,TW] One reviewer stated simply that the description of the oil thickness algorithm was limited, and suggested this study's final report should include expanded information on the technical approach

1. Quantification of Slick Thickness:

1.5–Are the assumptions of the oil thickness algorithm input clearly defined and appropriate (see Sections 2.2.4, 3.1.3, and 3.2.3)? If yes, explain why. If not, explain how those assumptions could be defined more clearly. Provide a rationale for your answer about the appropriateness of the assumptions of the oil thickness algorithm input.

for the oil thickness algorithm and details about the algorithm inputs and handling of the variables.[OG] One reviewer did not respond to this charge question due to lack of expertise.[NM]

Based on expertise as an acoustic measurement SME, one reviewer stated that the oil thickness algorithm itself was rather simple, and described it as follows: "the thickness is defined to be the time difference of arrival for the two interface returns, multiplied by the sound speed and divided by 2." This reviewer commented that it did not appear there were any invalid algorithm assumptions that would cause a problem for this method; however, the reviewer emphasized (as described under Charge Questions 1.1–1.4) that it was difficult to evaluate the oil thickness algorithm assumptions because it was difficult to know exactly what some of those parameters (sound speed) were based on the limited information provided in the draft final report.[TW]

Another reviewer also commented that it did not appear there were any problems with the algorithm assumptions that were provided in the draft final report; however, this reviewer qualified that comment by stating that the limitations and expected error ranges were missing in the draft final report and should be included in this study's final report to understand the algorithm assumptions as well as the expected accuracy and measurement error. This reviewer emphasized that all field measurements have limits on their validity and should have known expected accuracy. The reviewer had "searched in vain" throughout the draft final report for serious derivation of the oil thickness algorithm method and its range of application.[BL]

The two reviewers that stated evaluating the oil thickness algorithm assumptions was difficult given the limited information in the draft final report, also provided examples.[BL,TW] These examples are summarized below.

Based on expertise as an acoustic measurement SME, one reviewer commented about some of this study's parameters (sound speed) for the oil thickness algorithm assumptions that were difficult to evaluate based on the limited information provided in the draft final report. As an example of some gaps in the description of the oil thickness algorithm in the draft final report that made evaluating the algorithm assumptions difficult, this reviewer pointed to Section 2, which had no mention of how the temperature was used to convert to sound speed. This reviewer questioned whether a harmonic mean sound speed was used for this study because the sound speed parameters used for this study were not clearly defined in the draft final report. This reviewer also questioned how the top of the slick was determined for the temperature measurements (which were in turn required to calculate sound speed), given that the thermocouples were fixed in place.

This reviewer had noted during the panel meeting that BSEE's written answers to the peer reviewer questions (see Section 7 (Appendix C)) had clarified that this study did <u>not</u> use the harmonic mean sound speed. This reviewer emphasized that using harmonic mean sound speed would be the correct approach to acoustic measurement. To obtain the harmonic speed of sound, it

1. Quantification of Slick Thickness:

1.5–Are the assumptions of the oil thickness algorithm input clearly defined and appropriate (see Sections 2.2.4, 3.1.3, and 3.2.3)? If yes, explain why. If not, explain how those assumptions could be defined more clearly. Provide a rationale for your answer about the appropriateness of the assumptions of the oil thickness algorithm input.

was essential to know the location of the top of the slick and to measure the temperature gradient in the slick. As this reviewer commented under Charge Question 1.1, the draft final report was very unclear about how the researchers obtained the temperature measurement and how the top of the slick was determined. This reviewer stated that the researchers made an assumption about where the top of the slick was, but emphasized that this critical assumption was not clearly described in the draft final report.

This reviewer also noted during the panel meeting that BSEE's written answers to the peer reviewer questions (see Section 7 (Appendix C)) referred to the Supplemental Information (see Section 1.4.1) provided for the peer review, but this reviewer stated that the assumption the researchers made to identify the top of the slick was also not clearly described in the Supplemental Information (see Section 1.4.1). This reviewer emphasized that the purple line in the graph in the Supplemental Information (see Section 1.4.1) should not be a straight line, and questioned the validity of the material the researchers had provided in the Supplemental Information (see Section 1.4.1) for the peer review.[TW]

Another reviewer questioned the degree of horizontal spatial averaging by this acoustic measurement method, assuming that the return signal was not giving a specific point reading from the returning sonar. This reviewer expressed concerns that this could be a problem if this acoustic method is extended beyond the laboratory ISB experiments using pure fresh oil to actual oil spills where there may be large variations in the degree of weathering for different oil patches collected within the same ISB boom system.[BL]

1. Quantification of Slick Thickness:

1.6–What are the strengths and weaknesses of the slick thickness determination methods? Provide a rationale for each identified strength or weakness.

Three reviewers provided comments on strengths of the slick thickness determination methods.[OG,BL,TW] All four reviewers provided a range of comments on weaknesses of the slick thickness determination methods along with more detailed explanations about some of those identified weaknesses.[OG,BL,NM,TW]

Strengths

One reviewer, based on expertise as an acoustic measurement SME, stated that the strength of the slick thickness determination method was the simplicity associated with making measurements of the travel time for echoes. This reviewer emphasized again that this acoustic methodology was

1. Quantification of Slick Thickness:
1.6–What are the strengths and weaknesses of the slick thickness determination methods? Provide a rationale for each identified strength or weakness.

already proven in a variety of settings, including studies measuring layers of oil using broadband echo sounders[4] recently reported in the literature.[TW]

Another reviewer, based on expertise with ISB in open water conditions, commented that the use of acoustic sensors could likely be included in some autonomous underwater vehicle (AUV) or placed on the boom skirt to relay data to the ISB operations response team prior to starting ISB. This reviewer nevertheless identified two potential factors that would not necessarily be a drawback to this acoustic slick thickness measurement method for actual oil spill responses deploying ISB in offshore open water conditions. These two factors were:

- The reviewer pointed to Figure 13 in the draft final report that illustrated the acoustic measurement method becomes less reliable after significant burning begins. Based on reviewing Figure 13, this reviewer speculated that errors of 50% were possible in the slick thickness determination methods used in this study.
- The reviewer observed again that after boil over (subsurface water boiling) began, oil slick thickness became undefinable (or as this reviewer stated previously, the whole concept of an oil-water layer broke down).

The reviewer commented that boil over (subsurface water boiling) was a function of the artifice of this study's laboratory ISB experiments conducted in shallow confined pans. Other experiments in open ocean conditions have shown that subsurface water circulation prevents a dramatic increase in water temperature (e.g., the NIST mesoscale experiments in 1993).

With respect to burn rate, based on expertise with ISB in open water conditions, this reviewer commented that the draft final report illustrated, similar to past published reports (such as the study cited in Table 1), that there was a relatively constant burn rate for most of the laboratory ISB experiments (burn tests) with a gentle falloff as the thickness changed from over 10 mm to the limit of 2 mm thickness to sustain combustion for ISB. In making that comment, the reviewer excluded the burning during boil over (subsurface water boiling) where the greater exposed surface area temporarily (and artificially) increased the burn rate. The reviewer noted that burn rate is usually considered as relatively independent of oil type; however, the reviewer acknowledged that ASTM F-1788 publishes minor variations that actually depend upon the specific oil.

This reviewer concluded by stating that burn area and burn duration determines oil volume consumed by fire during ISB or transformed into unburned smoke particles (the latter probably about 10% of the oil mass), leading this reviewer to state that there was little value to determining slick thickness measurements during ISB operations in offshore open water conditions. This reviewer commented that such slick thickness measurements might be useful, depending upon the

[4] This reviewer referred to similar work conducted in "static" environments where the oil was not ignited (e.g., Bassett et al., JASA 137(1), EL32-EL38, 2015) that measured 40 mm thick layers of oil using broadband echo sounders operating between 200-300 kHz).

1. Quantification of Slick Thickness:
1.6–What are the strengths and weaknesses of the slick thickness determination methods? Provide a rationale for each identified strength or weakness.

particular ISB operations configuration, in providing an estimate of new oil volume captured during ISB as a redundant check on oil volume burned during ISB.[BL]

Finally, another reviewer commented that the most valuable strength was the fact that the researchers made this slick thickness determination method possible at least under the controlled setting of the laboratory ISB experiments. This reviewer believed that just the fact that a measuring tool was created, provided the potential for more elaborate laboratory testing to understand many other things, for example, to test oil burning rates under different levels of emulsifications.[OG]

Weaknesses

One reviewer, based on expertise as an acoustic measurement SME, stated that the main weakness of the slick thickness determination method was the requirement to measure *in-situ* temperature over very fine scales and vertically referenced to the oil slick (i.e., oil temperature gradient), in order to convert the measurements of travel time to distance. This reviewer emphasized again that identifying the location of the top of the slick, which is required to generate a temperature profile, seemed a particularly difficult part of applying this acoustic measurement method. This reviewer was not sure based on the results provided in the draft final report, if the researchers actually had a feasible approach to identify the top of the ignited slick. This reviewer expressed concerns that BSEE's written answers to the peer reviewer questions (see Section 7 (Appendix C)) did not address the issue of determining valid temperature profiles for the laboratory ISB experiments, given the straight-line-fit approach to the upper interface of the slick reported by the researchers.

This reviewer identified a second weakness as the requirement for knowledge of the temperature-dependent sound speed of oils, which could only be measured over a finite range of temperatures, and must be calculated for each type of oil (or oil/water emulsion) used.[TW]

Another reviewer stated that a weakness of the slick thickness determination method was related to the varying levels of emulsification throughout the slick during ISB in offshore open water conditions, and that emulsification variability will be a real challenge for accurate calibration of sound transducers. The reviewer noted that emulsions were not included in this study's laboratory ISB experiments.[NM]

<u>Transducers</u>

Two reviewers noted weaknesses related to the transducers for the acoustic measurement of slick thickness.[OG,NM] One of those reviewers stated that a weakness was that slick thickness was measured during the laboratory ISB experiments only at the points in the oil slick where each of the transducer probes were placed and did not represent the entire profile of the oil slick. This reviewer also stated that another weakness was that accurate calibration of sound transducers will be difficult with varying temperatures within the burning oil slick during ISB.[NM]

1. Quantification of Slick Thickness:

1.6–What are the strengths and weaknesses of the slick thickness determination methods? Provide a rationale for each identified strength or weakness.

The second of those two reviewers commented that the main operational challenge was to obtain and synchronize the sufficient aerial photography (and the proper geo-rectification) necessary to measure slick area with the proper deployment of the acoustic system to measure slick thickness, which this reviewer stated should collect acoustic measurements from instruments at an array of points under the ISB boom system, when possible under a specific range of sea state conditions. This reviewer commented that the weakest element for this slick thickness determination method was the limitations faced for testing on ISB operations in offshore open water conditions. Based on expertise with aerial mapping of oil spills, this reviewer stated that the success of tactical operations at sea requires the control of many variables that only occur under a limited window of sea state conditions.[OG]

The first of those two reviewers, based on expertise leading ISB operations in offshore open water conditions, stated that it was not easy to envision how sufficient transducer probes could be deployed from an operational perspective throughout the varying oil slick thickness within a towed ISB boom system to provide useful information during ISB operations in offshore open water conditions. This reviewer envisioned potentially using a netting structure suspended below an ISB boom system with numerous fixed transducers. The reviewer noted that floating debris would be a problem for transducers in open water conditions. This reviewer commented that ROV deployment would be very expensive and was not practical to cover several ISB boom systems at the same time.[NM]

Safety

One reviewer stated that Section 4 (Transitioning Towards Operational Environments) of the draft final report did not address issues regarding hazardous conditions during large-scale ISB operations. The reviewer observed that the draft final report mentioned some practice was needed to develop skills to negotiate the ROV under the burn for the small-scale ISB experiments performed in a laboratory setting. The reviewer noted that apparently some equipment was damaged (e.g., camera melted) during the laboratory ISB experiments.

Based on expertise with ISB in offshore open water conditions, this reviewer stated that large-scale ISB operations are much more dangerous to both personnel and equipment, placing significantly greater demands on both. This reviewer emphasized that safety, in particular, must be a major consideration in any new modification to oil spill response. The reviewer suggested that this study's final report should describe the expected training and precautions to allow for implementing this slick thickness determination method successfully with minimum risk to operators and low potential for equipment damage.[BL]

3.2.2 Quantification of Slick Area Charge Questions

2. Quantification of Slick Area:
2.1–Are the methods used to measure the surface area of the burning slick valid? If yes, explain why these methods are valid. If not, how could the validity of the area measurement methods be improved or more clearly described?
The reviewers provided varied comments about whether the methods used to measure the surface area of the burning slick were valid: • One reviewer stated that the methods were valid;[OG] • One reviewer stated that it "appears" that the methods presented in the draft final report were valid;[NM] • One reviewer commented that although the methods seemed technically possible and the draft final report showed believable results, those methods were not clearly described in the draft final report;[TW] and • One reviewer questioned whether sufficient cameras and known reference points were used in the laboratory ISB experiments.[BL] Two reviewers provided comments about how the validity of the methods to measure the surface area of the burning slick could be improved.[BL,NM] These two reviewer's varied comments about the validity of, and suggestions to more clearly describe or improve the validity of, the area measurement methods are summarized in the subsection below at the end of this charge question. The reviewer that stated the methods used to measure the surface area of the burning slick were valid,[OG] as listed above, commented that the laboratory ISB experiments were based on the known geometry of the tank. This reviewer explained during the panel meeting that control points are necessary for geo-rectification of an image, and that it appeared this study used the corners of the tank. This reviewer stated that if this method was used for ISB in offshore open water conditions, the operators of an ISB boom system would know the length of the booming, which would allow for "deducting" the area for measurement under ISB. This reviewer commented during the panel meeting that the researchers needed to document both a testing data set as well as a calibration data set to provide sufficient information to understand the accuracy of the methods used to measure the surface area of the burning slick. This reviewer expressed concerns that the draft final report did not demonstrate validity or how the researchers determined calibration accuracy to ensure that the slick area measurement methods used in the laboratory ISB experiments resulted in accurate measurements. This reviewer argued that this study needed to demonstrate how the testing data from the laboratory ISB experiments were either different from, or consistent with, calibration data for the camera settings.[OG] The reviewer that stated it "appears" that the methods presented in the draft final report were valid,[NM] as listed above, also noted that those methods were part of existing technology frequently used for other applications. This reviewer commented that the validity of the laboratory ISB experiments could be improved by testing application of the methods used to measure the surface area of the burning slick in darkness. The reviewer commented that ISB operations in offshore open water conditions could extend into the night and this occurred several times during the DWH

2. Quantification of Slick Area:

2.1–Are the methods used to measure the surface area of the burning slick valid? If yes, explain why these methods are valid. If not, how could the validity of the area measurement methods be improved or more clearly described?

response.[NM]

The reviewer that commented although the method seemed technically possible and the draft final report showed believable results, as listed above, also emphasized that the methods used to measure the surface area of the burning slick were not clearly described in the draft final report.[TW] This reviewer stated that the description of the use of different numbers of cameras from multiple/different camera angles to measure the surface area of the burning slick in the draft final report did not include information necessary to evaluate the method, including the following issues identified in the draft final report:

- Inadequate information regarding how the presence or absence of fire was detected in the images and image processing.
- No description of what ancillary inputs were required to perform planar homography, so that these requirements could be evaluated in the context of an at-sea operation. The reviewer questioned whether presumably altitude and orientation were required to perform planar homography.
- Information provided in BSEE's written answers to the peer reviewer questions (see Section 7 (Appendix C)) suggested that a simple threshold was used to detect pixels containing fire, but the draft final report did not address potential difficulties related to lighting conditions, water surface reflections, or other potentially confounding issues.

As an example, during the panel meeting, this reviewer commented that the reflection from the fire onto the water surface will create problems with the methods used to measure the surface area of the burning slick.[TW]

One reviewer, as listed above, questioned whether sufficient cameras and known reference points were used in the laboratory ISB experiments.[BL] This reviewer commented that the researchers met the distortion challenge by using planar homography, which is a well-established technique to adjust different images (e.g., adjustments for angles and distances) to a common reference plane with a common length scale. The reviewer stated that this technique normally uses reference points to define that common plane. The reviewer emphasized that those reference points (or other points at a known location from these points) should be observable by all, or most, of the cameras. This reviewer pointed to page 42 of the draft final report, and commented that the researchers claimed that two cameras at opposite ends of the burn test were sufficient to eliminate false positive readings and smoke obscuration for the laboratory ISB experiments. This reviewer questioned that claim, and expressed concerns that unfortunately the necessary documentation to check that claim was missing from the draft final report.[BL]

Improving Validity of Area Measurement Methods

Two of the reviewers who provided comments about improving the validity of the methods to measure the surface area of the burning slick suggested evaluating the validity of this study's

2. Quantification of Slick Area:

2.1–Are the methods used to measure the surface area of the burning slick valid? If yes, explain why these methods are valid. If not, how could the validity of the area measurement methods be improved or more clearly described?

experimental methods used in the laboratory based on applicability to ISB in offshore open water conditions.[BL,NM]

One reviewer, based on expertise with ISB in offshore open water conditions, presumed that one purpose of this project was to do technology proof of concept to determine whether this experimental method could be advanced up the TRL levels to full operation, and if that was the case, that methods to measure the surface area of the burning slick in the laboratory ISB experiments should be scalable to ISB in offshore open water conditions. This reviewer stated that during the DWH response, measuring the surface area of the slick required observers in aircraft. The reviewer commented that this experimental method for the laboratory ISB experiments used multiple cameras taking simultaneous images, which this reviewer stated did not seem practical with aircraft. Overall, this reviewer anticipated that surface mapping of the burn area will always present challenges for ISB operations in offshore open water conditions.[BL]

Also based on expertise with ISB in offshore open water conditions, one reviewer emphasized that the challenge for the technology proof of concept for transitioning to ISB in offshore open water conditions will be designing a procedure/methodology to maintain constant and sustained fire area monitoring (in daylight and darkness) to capture an accurate burn volume. This reviewer further emphasized that the fire area is the most important and most significant value to the burn volume equation, and that the fire area is usually hard information to acquire. The reviewer stated that burn rate can be estimated, burn duration is easy to obtain and record, but determining fire area accurately is most challenging portion of the burn volume equation.[NM]

2. Quantification of Slick Area:

2.2–Are the numbers of images, heights, and angles from around the fire adequate for accurate area computations using the photogrammetric methods reported? Explain how the approach chosen could affect the validity of the methodology and results.

Similar to Charge Question 2.1, the reviewer's responses varied with respect to the adequacy of the numbers of images, heights, and angles from around the fire to obtain accurate area computations using the reported photogrammetric methods:

- One reviewer, based on expertise with photogrammetric methods, expressed concerns that the draft final report provided only a general idea of how the geo-rectification was achieved. This reviewer stated that the draft final report was missing the technical details necessary to evaluate the range of camera heights, distances, and angles, as well as the different viewing geometries used in the 30 burn tests for the laboratory ISB experiments.[OG]
- Another reviewer, based on expertise with photogrammetric methods, commented that it seemed the camera number and placement was adequate for the small burn tests in the laboratory ISB experiments. The reviewer questioned the validity of this study's approach;

2. Quantification of Slick Area:

2.2–Are the numbers of images, heights, and angles from around the fire adequate for accurate area computations using the photogrammetric methods reported? Explain how the approach chosen could affect the validity of the methodology and results.

however, regarding the planned placement and view angles for cameras during ISB operations in offshore open water conditions.[BL]

- One reviewer commented that the draft final report demonstrated believable results with three images, but suggested that this study's final report should include a more complete technical analysis that examined how the burn test results from the laboratory ISB experiments changed with number of images, height of images, and angles of images.[TW]
- One reviewer believed the characteristics of the data gathering were adequate, but did not have the expertise for evaluating this question.[NM]

Camera Heights, Distances, and Angles

The reviewer that expressed concerns that the draft final report provided only a general idea of the approach for achieving geo-rectification,[OG] acknowledged that the draft final report provided some details about the technical setup and connectivity of the cameras to convey this general idea. Based on expertise with photogrammetric methods, this reviewer argued that this study's final report should include more technical details that fully describe the geometry of the laboratory setting and the range of camera heights, distances, and angles used for the laboratory ISB experiments. In particular, this reviewer suggested that a sketch of the camera set-up describing the range of camera heights, distances, angles from around the fire would be very useful. This reviewer also suggested that it would be useful to include a sketch of the distribution of the cameras (e.g., distances, angles) to understand if there was an optimal set of geometric conditions to obtain the best photogrammetric results. This reviewer emphasized during the panel meeting that it was important that the final report describe clearly what the researchers found was the ideal geometry based on the laboratory ISB experiments.[OG]

The reviewer that commented the camera number and placement seemed adequate for the small burn tests in the laboratory ISB experiments,[BL] questioned the information provided in the draft final report about view angles. The reviewer commented that BSEE's written answers to the peer reviewer questions (see Section 7 (Appendix C)) indicated that this study's method worked for angles as large as 65 degrees. This reviewer, based on expertise with photogrammetric methods, stated that the view angle ideally should be less than 30 degrees from the vertical.

This reviewer also commented that the draft final report stated that distant cameras and lower resolution (150x150 pixels over burn/fire area) provided sufficient accuracy; however, the calculations used to justify this statement were unfortunately not included in the draft final report. The reviewer suggested that distance was important because IPIECA recommends a "safe" downwind distance for a thousand square meter ISB as 1 kilometer, a considerable distance from the fire.[BL]

2. Quantification of Slick Area:

2.2–Are the numbers of images, heights, and angles from around the fire adequate for accurate area computations using the photogrammetric methods reported? Explain how the approach chosen could affect the validity of the methodology and results.

Number of Images

The reviewer that commented the draft final report demonstrated believable results with three images, as listed above, suggested that believable results might indicate three images were sufficient; however, this reviewer commented that this study's final report should provide a more complete technical analysis.[TW]

As already noted under Charge Question 2.1, one reviewer pointed to page 42 of the draft final report, and commented that the researchers claimed that two cameras at opposite ends of the burn test were sufficient to eliminate false positive readings and smoke obscuration for the laboratory ISB experiments. This reviewer questioned that claim, and expressed concerns that unfortunately the necessary documentation to check that claim was missing from the draft final report.[BL]

Missing Results for all Laboratory ISB Experiments (Burn Tests)

One reviewer suggested that this study's final report should include a more complete technical analysis to explain how the laboratory ISB experiments (burn test) results changed with the number of images, height of images, and angles of images. In particular, this reviewer questioned why the draft final report did not describe any efforts to examine how the burn test results for the laboratory ISB experiments changed as a function of the number of images, or their locations. This reviewer suggested that it was possible to at least begin such an investigation, given that there were more than three images used with some burn tests.[TW]

One reviewer, based on expertise with photogrammetric methods, questioned whether the algorithm was capable of handling images collected at different camera heights and angles. This reviewer suggested that it would be necessary for the researchers to include with their reported results a description of whether similar burn rates were achieved by placing the cameras under different viewing geometries for the 30 burn tests in the laboratory ISB experiments.

This reviewer questioned why the draft final report did not include the results for each of the 30 burn tests in the laboratory ISB experiments, because conducting all those burn tests should provide the researchers information about the variables. The reviewer argued that it would improve the understanding of the limitations and merits of the whole approach to provide results about when this study's area measurement method did well, and when it did not (e.g., what camera geometry—heights, distances, angles—actually worked). This reviewer anticipated that all those burn tests did not happen exactly the same; therefore, providing results about the repeatability of the laboratory ISB experiments would be valuable and would reinforce understanding the validity of this study's methodology and results.

This reviewer suggested it was important to understand whether the algorithm was capable of handling views from different angles and distances. As an experienced unmanned aerial system

2. Quantification of Slick Area:
2.2–Are the numbers of images, heights, and angles from around the fire adequate for accurate area computations using the photogrammetric methods reported? Explain how the approach chosen could affect the validity of the methodology and results.
(UAS) operator, this reviewer anticipated that sufficient aerial views of the ISB in offshore open water conditions could be achieved on a single flight. This reviewer noted that, in practice, it can be difficult for pilots to fly a UAS at a fixed altitude and a fixed distance from the ISB. The reviewer also commented that an algorithm capable of handling views from different angles and distances will be important if using aircraft.[OG] **Camera Placement in Offshore Open Water Conditions** One reviewer questioned the validity of this study's area measurement method with respect to the technology proof of concept for the planned placement and view angles for cameras during ISB in offshore open water conditions. This reviewer asked whether the technology proof of concept for this methodology was based on planning to put the cameras on support vessels or deploy the cameras on their own floating or airborne platforms. The reviewer anticipated that the camera view angles could be unfavorable, magnifying the distortion problem identified in the burn tests for the laboratory ISB experiments, given the need to maintain a significant safety distance from ISB operations in offshore open water conditions and the impracticality of high mountings of the cameras on their own platforms in the open ocean.[BL] Another reviewer commented that the camera heights and angles might be different for ISB in offshore open water conditions if dealing with very large fires where there is oxygen starvation in the center creating low burn efficiency, resulting in very dark black smoke. Potential smoke obstructions could also occur with high winds, when the smoke plume could lay down relative to the water surface, causing potential smoke obscurations for application of this study's area measurement method.[NM] This reviewer, along with another reviewer, explained during the panel meeting that the center of a burning slick may be oxygen starved, and the oxygen-starved part of the burning slick may burn less efficiently during ISB operations in offshore open water conditions.[NM,BL] During the panel meeting, all four reviewers questioned whether this study's area measurement method could address smoke obscuration of the oil-water (or fire-water) interface during ISB in offshore open water conditions, and whether this method could make corrections for such smoke obscuration in determining the surface area of the burning slick.[OG,BL,NM,TW]

2. Quantification of Slick Area:
2.3–Does the report adequately address the methods to account for errors from obstructions and limited angles/heights/distances? Explain how the methods used to account for errors could affect the validity or scientific merit of the methodology and results.
One reviewer, based on expertise with photogrammetric methods, suggested that this study's final report should include more technical details about the methods to account for errors from

2. Quantification of Slick Area:

2.3–Does the report adequately address the methods to account for errors from obstructions and limited angles/heights/distances? Explain how the methods used to account for errors could affect the validity or scientific merit of the methodology and results.

obstructions and limited angles/heights/distances. This reviewer expressed concerns that the methods used to account for errors from obstructions were briefly covered in the draft final report by only mentioning the causes for obstructions and how to address those challenges.[OG] Three reviewers commented that errors arising from smoke obstruction during ISB might affect the validity or scientific merit of this study's methodology and results, as summarized below.[BL,NM,TW]

Based on expertise with ISB in offshore open water conditions, one reviewer stated that for using this study's method during ISB operations in offshore open water conditions, obstruction from the ISB boom systems or other equipment would be relatively small compared to the surface area located within the ISB boom system.[BL]

Another reviewer, based on expertise with ISB in offshore open water conditions, noted that burns can last 12 hours or more during ISB operations in offshore open water conditions. This reviewer noted that this photogrammetric technology is not new, but commented that applying it to achieve constant fire area monitoring for large offshore burns 200 or 300 feet in diameter would be new.[NM]

One reviewer, based on expertise with photogrammetric methods, explained during the panel meeting that poorly chosen camera angles caused problems with fire reflection on the water surface in images from the laboratory ISB experiments (i.e., Figure 43 on page 42 of the draft final report). This reviewer emphasized that it was important to choose the correct camera angles for accurate measurement with planar homography techniques. The reviewer also emphasized that it was important to constantly adjust the camera angles to reduce problems such as fire reflection on the water surface in the images. Because improved accuracy may depend on constantly adjusting camera angles, this reviewer commented that a moving camera was necessary for accurate photogrammetric results. The reviewer noted that using multiple camera angles can greatly reduce problems with water surface reflections in the images.

This reviewer recommended that another approach to reduce and better account for errors would use a moving platform (i.e., a UAS) flying at an equidistance from the center of the surface area of the burning slick (and at different heights). This recommended approach would provide a 3-D (volumetric) perspective and other data can be captured (i.e., density of the smoke plume) that could improve validity for calculating the surface area of the burning slick. During the panel meeting, this reviewer commented that additional levels of camera heights would add more information to account for errors.[OG]

Smoke Obstruction

One reviewer, acknowledging lack of expertise in photogrammetric methods, suggested that the methodology seemed to account for errors of obstruction. Based on expertise with ISB in offshore open water conditions, this reviewer emphasized again that smoke obstructions can occur with high winds during ISB in offshore open water conditions, when the smoke plume can lay down

2. Quantification of Slick Area:

2.3–Does the report adequately address the methods to account for errors from obstructions and limited angles/heights/distances? Explain how the methods used to account for errors could affect the validity or scientific merit of the methodology and results.

relative to the water surface. This reviewer expressed concerns that such black and gray smoke might cause errors and affect the validity of this study's methodology.[NM]

Another reviewer commented that it appeared that occlusion issues due to obstructions were adequately solved with images from multiple angles around the fire. This reviewer emphasized that smoke obstruction was a more significant issue, and noted that the draft final report described smoke obstruction causing errors during the laboratory ISB experiments for both the visual and infrared cameras. The reviewer pointed to the photographs of ISB operations shown in Figure 1 on page 6 of the draft final report, and noted those photos indicated that billowing smoke would be a challenge when wind is present (see third panel of Figure 1). This reviewer argued that this issue of obstructions from billowing smoke from winds would be a difficult problem to overcome using the methodology presented in the draft final report. This reviewer recommended more emphasis on investigating the use of infrared cameras, in particular, infrared cameras that identify a specific infrared wavelength.[TW]

One reviewer commented that smoke was not a problem for the small-scale burn tests for the laboratory ISB experiments discussed in the draft final report; however, based on expertise with ISB in offshore open water conditions and knowledge of the relevant literature, this reviewer stated that smoke obscuration will cause errors. The reviewer noted that NIST had reported 10-15% of the mass of the oil had converted into smoke particles for large-scale open water ISBs.

Based on expertise with photogrammetric methods, this reviewer expressed concerns that, at best, the methodology presented in the draft final report might be able to estimate the smoke area for ISB operations in offshore open water conditions. The reviewer pointed to page 42 of the draft final report, which explained the smoke area may be indistinguishable from, or obscuring of, the burn area, even in the infrared range. The reviewer questioned the researcher's suggestion in the draft final report that multiple cameras and dynamic phasing of the imagery can overcome the "false positive" burn area by looking at the flame from different angles at different times. The reviewer also questioned the statement in the draft final report that flame may be separated from smoke by using a different infrared frequency band.

This reviewer concluded by stating that image analysis, and camera placement and timing, will be problematic for this study's methodology because of smoke obscuration during ISB in offshore open water conditions. The reviewer, based on expertise with ISB in offshore open water conditions and knowledge of the relevant literature, emphasized that the smoke area can be at different temperatures, encompass the entire smaller burn area, and/or change location due to wind fluctuation. As an example, the reviewer noted that films of ISBs during the DWH response show flame appearing well above the water surface and surrounded by smoke.[BL]

2. Quantification of Slick Area:

2.4–Are the assumptions of the area algorithm input with respect to burning area of the slick clearly defined and appropriate (see Sections 2.1.1, 3.1.1, and 3.2.1)? If yes, explain why. If not, explain how those assumptions could be defined more clearly. Provide a rationale for your answer about the appropriateness of the assumptions of the area algorithm input with respect to burning area of the slick.

All four reviewers expressed concerns about whether the assumptions of the area algorithm input with respect to the burning area of the slick were clearly defined and appropriate in the draft final report.[OG,BL,NM,TW]

Laboratory ISB Experiment (Burn Test) Results Necessary to Evaluate Area Algorithm

One reviewer stated that the assumptions of the area algorithm input with respect to the burning area of the slick were adequately addressed; however, this reviewer also emphasized that the draft final report did not provide the summary and comparison of results from the 30 burn tests from the laboratory ISB experiments that would actually be necessary to validate the area algorithm performance. Based on expertise with photogrammetric methods, this reviewer commented that the area of the ISB would be known by the length of the booming, suggesting that this would be important as an assumption for the area algorithm input.[OG]

Based on expertise with photogrammetric methods, another reviewer observed that for the area algorithm input, the burning area of the slick was observed from multiple cameras, each with a unique view angle (for ISB in offshore open water conditions, the reviewer suggested this might include elevation). The reviewer commented that the researchers met the subsequent distortion challenge by using planar homography, a well-established technique to adjust different images to a common reference plane with a common length scale (the water surface and the limits of the burning area of the slick) and that this technique normally uses reference points to define that common plane. The reference points (or other points at a known location from these points) should be observable by all, or most, of the cameras.

The reviewer commented that this study's final report should clarify how the method presented in the draft final report ensured that known reference points were used when smoke may have obscured the images, or alternatively, the number of cameras with a clear view that were sufficient to ensure the accuracy of the area algorithm if some cameras were obscured during the 30 burn tests for the laboratory ISB experiments. The reviewer commented that the draft final report "hints at" as low as two (2) cameras with a clear view of the reference points, but that seemed too few to this reviewer.

This reviewer also commented that page 40 of the draft final report noted the results from the 30 burn tests for the laboratory ISB experiments were used to empirically determine error and verify the limits of forming an accurate planar homography; however, because the draft final report did not provide the results from the 30 burn tests, it was difficult to know if those errors were within an acceptable range.[BL]

2. Quantification of Slick Area:

2.4–Are the assumptions of the area algorithm input with respect to burning area of the slick clearly defined and appropriate (see Sections 2.1.1, 3.1.1, and 3.2.1)? If yes, explain why. If not, explain how those assumptions could be defined more clearly. Provide a rationale for your answer about the appropriateness of the assumptions of the area algorithm input with respect to burning area of the slick.

Pixel Resolution

One reviewer commented that in BSEE's written answers to the peer reviewer questions (see Section 7 (Appendix C)), the researchers noted that only single RGB pixel results were used define flame on the water surface. This reviewer expressed concerns that the algorithm provided in BSEE's written answers to the peer reviewer questions (see Section 7 (Appendix C)) seemed "woefully inadequate." This reviewer stated that, at minimum, adjustments were needed to the algorithm to define flame only on the oil-water surface plane as opposed to flame in planes above the water surface. The reviewer emphasized that algorithm rules should be based at least on differences with surrounding pixels, not the absolute readings of any individual pixel. The reviewer stated that better infrared images will probably be required for more appropriate assumptions for the area algorithm input with respect to burning area of the slick. In the reviewer's judgment, this was one of the most important gaps in the draft final report if BSEE's plan is to move this technology up the TRL ladder.[BL]

Although acknowledging lack of expertise in photogrammetric methods, one reviewer emphasized that it was noticeable that the burn area demonstration photos in Figure 11 on page 15 of the draft final report seemed to show some normalizing of areas where odd shapes of fire occurred during the laboratory ISB experiments. This reviewer expressed concerns that, if such normalizing was indeed conducted for the area algorithm, the margin of error or accuracy was not clearly defined in the draft final report. More specifically, this reviewer suggested that this study's final report should provide more technical details to clarify what pixel resolution was used and how much estimation or "rounding off" was done with respect to those odd fire shapes in the burn tests for the laboratory ISB experiments. The reviewer noted that large ISBs in offshore open water conditions will have many of these odd fire shapes and edges throughout the burning area of the slick. During the panel meeting, this reviewer acknowledged that "normalization" would be required for some areas within the burning slick that will have odd fire shapes and "sharp" fire edges.[NM]

More Technical Details Necessary for Steps for Rectified Views

Similarly, another reviewer commented that it was difficult to provide comments on Charge Question 2.4 without more detailed knowledge about the fire detection algorithm (step 6 on page 16 of the draft final report) or examples of how an external length scale such as a boom were used to quantify the burning area of the slick (step 8 on page 16 of the draft final report), for which details were not provided in the draft final report. Also, the reviewer found the very general information provided in BSEE's written answers to the peer reviewer questions (see Section 7 (Appendix C)) inadequate for the reviewer to respond with comments for this charge question.[TW]

2. Quantification of Slick Area:

2.4–Are the assumptions of the area algorithm input with respect to burning area of the slick clearly defined and appropriate (see Sections 2.1.1, 3.1.1, and 3.2.1)? If yes, explain why. If not, explain how those assumptions could be defined more clearly. Provide a rationale for your answer about the appropriateness of the assumptions of the area algorithm input with respect to burning area of the slick.

Calibration Accuracy

Based on expertise with photogrammetric methods, one reviewer stated during the panel meeting that it would be necessary to compare the burn test results from the laboratory ISB experiments to calibration tests in order to evaluate the appropriateness of the assumptions of the area algorithm input with respect to burning area of the slick. The reviewer emphasized that this study needed information on calibration accuracy (e.g., camera settings) to understand the accuracy of the algorithm inputs for the slick area measurement methods. The reviewer stated again that the laboratory ISB experiment (burn test) results must be compared with equipment calibration results to evaluate if this study's method resulted in accurate measurements.

As an example, this reviewer stated during the panel meeting that the draft final report did not explain the calibration of the infrared cameras. The reviewer emphasized that a more accurate approach would require demonstrating a calibration point, and using that to normalize any offset or error from the infrared cameras.[OG]

2. Quantification of Slick Area:

2.5–What are the strengths and weaknesses of the methods for the determination of the area(s) of the burning slick? Provide a rationale for each identified strength or weakness.

Two reviewers mentioned, in general terms, a strength of the methods for determining the area(s) of the burning slick.[NM,TW] One of those reviewers commented that the strength was using automated equipment to "tirelessly" (i.e., not manually) and more accurately perform fire (burn) area estimation.[NM] Another of those reviewers commented that the main strength of the methods for determining the area(s) of the burning slick was the simplicity of the measurement. Given that camera images are routinely collected using manned aircraft and drones at sea, and that such camera images have been used previously to measure the sizes of objects, it seemed to this reviewer that this technology could be readily applied to ISBs.[TW]

All four reviewers identified weaknesses in the methods for determining the area(s) of the burning slick. One reviewer commented about reference points,[OG] and two reviewers commented about smoke obscuration,[BL,TW] as summarized in the subsections below.

One reviewer commented that the weaknesses included unclear definition of the margin of error or accuracy, for example, the draft final report did not clearly define how the estimation or "rounding off" was conducted to determine the area(s) of the burning slick for the laboratory ISB experiments. Under Charge Question 2.4, this reviewer noted that large ISBs in offshore open water conditions will have many of these odd fire shapes and edges throughout the burning area of

2. Quantification of Slick Area:

2.5–What are the strengths and weaknesses of the methods for the determination of the area(s) of the burning slick? Provide a rationale for each identified strength or weakness.

the slick. During the panel meeting, this reviewer acknowledged that "normalization" would be required for some areas within the burning slick that will have odd fire shapes and "sharp" fire edges.[NM]

Reference Points

One reviewer, based on expertise with photogrammetric methods, stated that the area of the ISB can be accurately calculated with aerial views and with references from the positions of the vessels. This reviewer commented nevertheless that the draft final report did not address the algorithm or the researcher's plan for calculation of the area of a burning slick. This reviewer stated the draft final report had no mention about the use of dynamic control points and how such control points would be incorporated for the mapping, or the area algorithm to calculate the area(s) of the burning slick.

This reviewer emphasized that control points on the open field are a must. If this method for determining the area(s) of the burning slick will be taken to the next TRL, this reviewer recommended investigating much higher altitudes for capturing images of the laboratory ISB experiments (burn tests). The reviewer stated that using oblique imagery and using such low angles as shown in the draft final report can cause more specular reflections and distortions that complicate the image processing and would cause inaccurate results. This reviewer emphasized that this problem can be solved by using higher altitudes for capturing the photographic images. The reviewer recommended again that a UAS with thermal and high resolution RGB could help to minimize problems with reflections and distortions causing inaccurate results for image processing.[OG]

Smoke Obscuration

One reviewer commented that the most significant challenge that burn area measurement by visual and infrared imaging would face in an operational application would be smoke obscuration of the burn area by the smoke produced during ISB in offshore open water conditions. The reviewer commented again that smoke was not a problem for the small-scale burn tests for the laboratory ISB experiments discussed in the draft final report. Although smoke was less of a problem from small contained burns such as the CRREL ice burn tests, the reviewer emphasized that the burn area during the laboratory ISB experiments was more constrained to begin with. The reviewer commented that multiple cameras seemed useful in cases where the flame can be clearly distinguished from the smoke for at least one view, allowing correction for such artifacts as flame reflection from the water surface.

Based on expertise with ISB in offshore open water conditions and knowledge of the relevant literature, this reviewer commented again that smoke obscuration will cause errors. The reviewer noted that NIST had reported 10-15% of the mass of the oil had converted into smoke particles for large-scale open water ISBs.

2. Quantification of Slick Area:

2.5–What are the strengths and weaknesses of the methods for the determination of the area(s) of the burning slick? Provide a rationale for each identified strength or weakness.

This reviewer again expressed concerns that, at best, the methodology presented in the draft final report might be able to estimate the smoke area for ISB operations in offshore open water conditions. The reviewer pointed to page 42 of the draft final report, which explained the smoke area may be indistinguishable from, or obscuring of, the burn/fire area, even in the infrared range. The reviewer again questioned the researcher's suggestion in the draft final report that multiple cameras and dynamic phasing of the imagery can overcome the "false positive" burn area by looking at the flame from different angles at different times. The reviewer also questioned again the statement in the draft final report that flame may be separated from smoke by using a different infrared frequency band.

Similar to Charge Question 2.3, this reviewer concluded by stating that image analysis, and camera placement and timing, will be problematic for this study's methodology because of smoke from ISB in offshore open water conditions. The reviewer, based on expertise with ISB in offshore open water conditions and knowledge of the relevant literature, emphasized again that the smoke area can be at different temperatures, encompass the entire smaller burn area, and/or change location due to wind fluctuation. As an example, the reviewer noted that films of ISBs during the DWH response show flame appearing well above the water surface and surrounded by smoke.[BL]

Another reviewer emphasized that the main weakness of this study's methods for determining the area(s) of the burning slick seemed the obscuration of the burn area by blowing, billowing smoke, and pointed to example ISB photographs in Figure 1 on page 6 of the draft final report that showed billowing smoke from ISB operations in offshore open water conditions. This reviewer stated that cameras cannot measure what they cannot see and expressed concerns that information in the draft final report indicated this smoke obscuration issue was present even for cameras operating at infrared wavelengths during the burn tests for the ISB laboratory experiments. This reviewer also expressed concerns that if blowing and billowing smoke are present for ISB in offshore open water conditions, it could cause large biases in estimating the area(s) of the burning slick. The reviewer commented that these smoke obscuration problems remained largely unaddressed in the draft final report, but the smoke obscuration problems seemed solvable.[TW]

3.2.3 BSEE Study Report Charge Questions

3. BSEE Study Report:
3.1–To demonstrate the technology proof of concept—Does the report adequately address the methodology to accurately calculate the volume of the entire slick given the differences in thicknesses throughout the entire slick being burned? Explain how this affects the validity or scientific merit of the methodology and results.
All four reviewers commented that the draft final report did not adequately address the methodology to accurately calculate the volume of the entire slick given the differences in thicknesses throughout the entire slick being burned.[OG,BL,NM,TW] Two reviewers stated that this study actually did not include measurement of varying slick thickness throughout the entire slick being burned. Those two reviewers did not find any such results for this study's methodology in the draft final report. In fact, the researchers stated on page 53 of the draft final report: "For this project, we did not attempt to measure the spatial variations of the slick thickness."[BL,TW] Based on expertise as an acoustic measurement SME, one reviewer emphasized there were gaps in the methodology to calculate the volume of the entire slick given the differences in thicknesses throughout the entire slick being burned that must be addressed for making these measurements in a laboratory setting. The methodology gaps summarized by this reviewer are listed below: • **Temperature Profile**. In terms of the acoustically-derived slick thickness measurement, this reviewer emphasized that the measurement of the temperature profile of the oil slick needs refinement. Of particular importance is determining the height of the upper layer of the oil (i.e., the location of the oil/flame interface). The reviewer commented that this study seemed to use a visual approach for identifying the location of the oil/flame interface. Moreover, this reviewer emphasized that this study's results were not "self-consistent;" more specifically, the time-varying height of the oil/flame interface used to generate the temperature profiles did not match the acoustic thickness measurement. Based on expertise as an acoustic measurement SME, this reviewer commented that BSEE needed to establish a methodology to accomplish this with greater accuracy, and also to establish an uncertainty for this methodology. • **Spatial Variability in Slick Thickness**. The reviewer commented that this study did not attempt to measure spatial variations of slick thickness (see page 53 of the draft final report). This reviewer stated that the issue of determining a temperature profile was compounded by the potential for spatial variability in slick thickness. The reviewer acknowledged that it appeared this study's experimental setup for the laboratory ISB experiments would lend itself to such an investigation, even though it was not addressed by this study in the laboratory setting. • **Deployment of Sensors**. The reviewer emphasized that advancing this study's method beyond a laboratory setting would require deploying sensors under the slick, in the case of the acoustic measurement, or within the slick to determine the temperature profile. • **Basic Flaw that Knowledge of Slick Thickness Necessary before Performing Acoustic Measurement of Slick Thickness**. Overall, this reviewer expressed concerns that the need to deploy sensors within the slick leads to an apparent basic flaw in this study's slick area measurement method: measuring the temperature profile requires knowledge of the slick boundaries (or at least the upper boundary), which implies that the slick thickness may be

3. BSEE Study Report:
3.1–To demonstrate the technology proof of concept—Does the report adequately address the methodology to accurately calculate the volume of the entire slick given the differences in thicknesses throughout the entire slick being burned? Explain how this affects the validity or scientific merit of the methodology and results.

known before performing the acoustic measurement. This reviewer commented that there is no currently accepted method for making such a temperature profile measurement and noted that lack of such acceptable methods would certainly be a limitation on the proposed acoustic method described in the draft final report.[TW]

Based on expertise with ISB in offshore open water conditions, another reviewer commented that this study actually did not include measurement of varying slick thickness and thus it was not possible to comment on any methodology for measuring spatial thickness variation from the draft final report. In addition, this reviewer was uncertain about when more than one transducer was used in any of this study's laboratory ISB experiments. To achieve spatially varying thickness measurements, this reviewer commented that presumably, given that the acoustic signal was sufficiently focused, it would be necessary to have more than one transducer and that each of the multiple transducers must be spatially separated, or that it would be necessary to have a moving transducer that transits the burn area.[BL]

One reviewer stated that the draft final report "really did not" adequately address the methodology to accurately calculate the volume of the entire slick given the differences in thicknesses throughout the entire slick being burned. This reviewer commented that the burn volume calculation should have been the root of this study, and stated that the burn volume calculation should have been explained more thoroughly in the draft final report. The reviewer noted that the volume was reported incorrectly in units of area in square centimeters in Table 2 on page 28 of the draft final report.[NM]

Another reviewer commented that the draft final report did not provide the results obtained from the multiple laboratory ISB experiments conducted for this study. This reviewer expressed concerns that not demonstrating the repeatability of the laboratory ISB experiments affected this study's validity, because a problem existed if the researchers could not demonstrate how the acoustic system performed to measure slick thickness during repeated experiments. This reviewer emphasized that if the acoustic system worked, then the researchers should be able to demonstrate that this study's approach obtained similar results during the different ISB laboratory experiments (burn tests) or that this study's approach obtained results within reasonable variability. The reviewer recommended that this study's final report should provide data with the results from the multiple laboratory ISB experiments (over 30 burn tests). This reviewer suggested that a comparison of the results from the multiple laboratory ISB experiments was important to demonstrate when this study's approach worked and when it did not work. The reviewer also expressed concerns that the draft final report did not describe the main controlled and un-controlled variables, and emphasized that information on those main variables was necessary to understand the validation of results.[OG]

3. BSEE Study Report:

3.1–To demonstrate the technology proof of concept—Does the report adequately address the methodology to accurately calculate the volume of the entire slick given the differences in thicknesses throughout the entire slick being burned? Explain how this affects the validity or scientific merit of the methodology and results.

Sensor Deployment for ISB in Offshore Open Water Conditions

From an operational perspective, for technology proof of concept, one reviewer commented that it was very likely that there will be large spatial variations in slick thickness, given how oil is boomed for ISB in offshore open water conditions. This reviewer commented that operationally, the acoustic and temperature sensors must be deployed on an underwater vehicle—presumably an ROV or an AUV. The reviewer stated that such sensor deployment would likely present a large operational challenge given the difficulties in deploying such sensors under the ocean during even quiescent conditions, but this issue was not addressed in the draft final report.

Based on expertise as an acoustic measurement SME, this reviewer stated that the high acoustic frequencies used in the proposed methodology for this study would require very short range measurement (several meters, presumably), which would place an underwater vehicle only a few meters underneath ISB in offshore open water conditions. The reviewer expressed concerns that this close proximity to the ignited burn would seem to create significant risk to the underwater vehicle, its tether, etc.[TW]

3. BSEE Study Report:

3.2–To demonstrate the technology proof of concept—Does the report describe with reasonable accuracy how burn volumes, burn rates, and burn efficiencies are computed? If yes, explain why these computations are described with reasonable accuracy. If not, how could the report describe these computations more clearly or with improved accuracy?

All four reviewers commented that the draft final report did not describe with reasonable accuracy how burn volumes, burn rates, and burn efficiencies were computed.[OG,BL,NM,TW]

One reviewer commented that the benchmarking for the laboratory ISB experiments was not adequately described in the draft final report. This reviewer stated that determining the accuracy of computations for the burn volume, burn rate, and burn efficiency measurements in the laboratory requires a valid benchmark. This reviewer expressed the following concerns about the benchmarking with respect to the draft final report:

- The benchmark used in this study relied on converting the mass of the oil to its volume, and dividing the volume by the cross-sectional area of the burn test container. The conversion of mass to volume requires the density, which is a function of temperature; however, the reviewer stated that the draft final report showed that the temperature was not constant throughout the oil layer for the laboratory ISB experiments.
- The draft final report also quoted a density-temperature relationship, which the reviewer noted was unreferenced and should be documented to understand computational accuracy.
- The draft final report did not describe how the spatially (at least vertically) varying and

3. BSEE Study Report:

3.2–To demonstrate the technology proof of concept—Does the report describe with reasonable accuracy how burn volumes, burn rates, and burn efficiencies are computed? If yes, explain why these computations are described with reasonable accuracy. If not, how could the report describe these computations more clearly or with improved accuracy?

time-varying temperature of the oil was used to find a density.

This reviewer also commented about the importance of conducting uncertainty analysis (e.g., propagation of error) on this study's methodology for demonstrating technology proof of concept to extend this method to ISB in offshore open water conditions. The reviewer commented that no uncertainty analysis was conducted on the methodology for the draft final report. The reviewer also stated that the draft final report did not provide any estimates of the uncertainty for the individual components (e.g., arrival time, sound speed, pixel flame detection) of this study's methodology.[TW]

One reviewer commented that computational accuracy was not described properly in the draft final report because it did not provide all results obtained from the multiple laboratory ISB experiments conducted for this study. This reviewer expressed concerns that to describe the computations more clearly or with improved accuracy, the researchers should provide results that demonstrated how the burn volume, burn rate, and burn efficiency measurements performed from the repeated laboratory ISB experiments. The reviewer commented that the draft final report could have been improved by providing an analysis of performance over the series of 30 burn tests for laboratory ISB experiments.

This reviewer also commented that when using the thermal sensors, it was important to always have reference points with known temperatures. By using known reference points, after a thermal image is obtained, it could then be corrected for any thermal emissivity offsets. This reviewer emphasized that there were no thermal control points shown in the draft final report and also there was no description of calibration accuracy for the thermal cameras in the draft final report.[OG]

Another reviewer commented that although the calculations of burn volume, burn rate, and burn efficiency were simple and straightforward; however, it was unfortunately not possible from the draft final report for this reviewer to "truly assess" the necessary accuracy of these numbers because no measurements had error bars. This reviewer stated that the computations in the draft final report would be more clearly described if the draft final report included information on the actual values for the parameters used and the expected uncertainties in these parameters in the researcher's calculations.

As an example, the reviewer pointed to the material discussed on pages 26-28 of the draft final report (Section 2.3 Volume, Burn Rate and Burn Efficiency Measurements) and stated that was confusing to the reviewer. The reviewer noted that the draft final report showed some differences between burn rate as measured by mass (volume) loss and burn rate as calculated by thickness change. This reviewer questioned whether the difference as simply due to water loss in the mass (volume) calculation.

3. BSEE Study Report:
3.2–To demonstrate the technology proof of concept—Does the report describe with reasonable accuracy how burn volumes, burn rates, and burn efficiencies are computed? If yes, explain why these computations are described with reasonable accuracy. If not, how could the report describe these computations more clearly or with improved accuracy?
More specifically, this reviewer pointed to the bottom of the graph for Figure 25 on page 27 of the draft final report, which indicated that the burn rate decreased significantly for slick thickness from 6 to 10 mm. The reviewer emphasized that this strange result contradicted the expected burn rates cited from the Buist, et al (2003) study in Table 1 above Figure 25. Based on expertise with ISB in offshore open water conditions, this reviewer stated that it would be expected that increased oil slick thickness would act as insulation, reducing heat loss to the water and producing a higher burn rate. The reviewer assumed that the anomalous results in the graph for Figure 25 are due to lack of steady burning early on, when the oil slick thickness was high, combined later on with the beginning of boil over (subsurface water boiling). This reviewer had commented under previous charge questions that boil over (subsurface water boiling) was a function of the artifice of this study's laboratory ISB experiments conducted in shallow confined pans. If those anomalous results were due to boil over (subsurface water boiling), the reviewer emphasized that should be clearly explained in this study's final report.[BL] Finally, another reviewer commented that the draft final report could describe the computation results more clearly and with improved accuracy. As an example, this reviewer pointed to the graph for Figure 23 on page 26 of the draft final report (Section 2.3 Volume, Burn Rate and Burn Efficiency Measurements) and noted that Figure 23 did not depict the Y-axis "label" and "units."[NM] As an editorial note, one reviewer commented that Table 2 on page 28 of the draft final report should not have used cm^2 as a measurement unit for burn volume.[BL]

3. BSEE Study Report:
3.3–To demonstrate the technology proof of concept—Are the limitations and uncertainties clearly identified and adequately characterized for the determination of burn volumes, burn rates, and burn efficiencies? If yes, explain why. If not, how could the limitations and uncertainties for the determination of burn volumes, burn rates, and burn efficiencies be described more clearly or characterized with improved accuracy?
Three reviewers commented that the draft final report did not clearly identify and adequately characterize the limitations and uncertainties for the determination of burn volumes, burn rates, and burn efficiencies.[OG,BL,TW] One reviewer commented that the draft final report adequately characterized the limitations and uncertainties for the determination of burn volumes and burn rates; however, burn efficiency was not clearly described or adequately characterized. This reviewer also commented that burn rates and burn efficiency results in the draft final report correlated well with many previous laboratory studies.[NM] Based on expertise with ISB in offshore open water conditions, one reviewer commented that "the

3. BSEE Study Report:

3.3–To demonstrate the technology proof of concept—Are the limitations and uncertainties clearly identified and adequately characterized for the determination of burn volumes, burn rates, and burn efficiencies? If yes, explain why. If not, how could the limitations and uncertainties for the determination of burn volumes, burn rates, and burn efficiencies be described more clearly or characterized with improved accuracy?

short answer to this question is no." This reviewer emphasized again that the draft final report did not provide any error bars on any of the graphs. The reviewer noted that the draft final report claimed that this study conducted multiple laboratory ISB experiments (30 burn tests) that could be used to empirically determine error; however, the relevant data and calculations were not included in the draft final report. As an example, this reviewer stated that one useful graph could present results for burn rate calculation accuracy versus peak wave height. Another useful graph could present results for slick area estimate uncertainty as a function of average view angle. Overall, this reviewer commented that this lack of reported data and results from the laboratory ISB experiments seemed an obvious oversight for what would otherwise be considered a good research effort.[BL]

Based on expertise as an acoustic measurement SME, one reviewer commented that the draft final report did not clearly identify and adequately characterize the limitations, uncertainties, and potential pitfalls of this proposed methodology for determination of burn volumes, burn rates, and burn efficiencies. This reviewer identified two fundamental limitations:

- **Dynamic Nature of ISB in Offshore Open Water Conditions**: This reviewer stated that the most fundamental limitation for technology proof of concept to extend this method to ISB in offshore open water conditions was the dynamic nature of ISBs. This reviewer noted that the two reviewers with expertise with ISB in offshore open water conditions had discussed during the panel meeting that spilled oil often enters an ISB boom system as it is towed. The reviewer stated that two factors will change the slick thickness within the ISB boom system: 1) the amount of oil entering, and 2) the amount of oil being burned off; however, only one factor affects the burn rate: the amount of oil being burned off. This reviewer concluded that this study's method for measuring the slick thickness alone without knowledge of the amount of oil entering an ISB boom system was insufficient for estimating the burn rate.
- **Sound Speed of Oil**: This reviewer stated that another fundamental limitation was the need for knowledge of the sound speed of the oil. The reviewer explained that this requires knowledge of the oil temperature profile, for which there is no established method, but it also requires knowledge of the temperature-dependent sound speed. The reviewer also explained that current methods for establishing this sound speed require empirical testing with oil samples. This reviewer expressed concerns about how knowledge of the sound speed of oil could be achieved for oil that was weathered at the surface, or turned into an emulsion. The reviewer stated that was unclear whether this study's methodology could provide knowledge of the sound speed of weathered/emulsified oil, and commented that this weathered/emulsified oil issue was not addressed in the draft final report.[TW]

Finally, another reviewer commented that the draft final report did not clearly identify the limitations and uncertainties for the determination of burn volumes, burn rates, and burn

3. BSEE Study Report:
3.3–To demonstrate the technology proof of concept—Are the limitations and uncertainties clearly identified and adequately characterized for the determination of burn volumes, burn rates, and burn efficiencies? If yes, explain why. If not, how could the limitations and uncertainties for the determination of burn volumes, burn rates, and burn efficiencies be described more clearly or characterized with improved accuracy?
efficiencies. The reviewer emphasized that it would be necessary for the researchers to include the analysis and results that demonstrated how the burn volume, burn rate, and burn efficiency measurements performed over the series of 30 burn tests for the laboratory ISB experiments in order to identify the limitations and uncertainties.[OG]

3. BSEE Study Report:
3.4–To demonstrate the technology proof of concept—What are the strengths or weaknesses of the methods used for the computations? Provide a rationale for each identified strength or weakness.
Two reviewers commented about strengths of the methods used for the computations,[OG,BL] and all four reviewers commented about weaknesses.[OG,BL,NM,TW] **Strengths** Based on expertise with ISB in offshore open water conditions, one reviewer commented that the strength of the methods used for the computations in the draft final report was that the calculation methods were simple and easily understood. This reviewer stated that understandability is important when explaining results during an oil spill emergency to non-technical decision-makers.[BL] Another reviewer also commented that the strength of this study's methods was the approach itself, using basic arithmetic computations based on the observations of the burn rate, thickness change, etc. The reviewer believed this study was "a genuine great effort put together by the authors" that represented "a strong foundation for further development of science."[OG] **Weaknesses** Based on expertise with ISB in offshore open water conditions, one reviewer stated that while the draft final report established technology proof of concept for measuring slick thickness during the laboratory ISB experiments, the draft final report did not give a rationale for substituting already well-documented burn rates for "something calculated on the fly" during an oil spill emergency ISB operation. Moreover, this reviewer stated that it was difficult to evaluate this method's accuracy because some of the more complex calculations, such as signal-to-noise ratio from the acoustic measurements and view correction uncertainty using planar homography were not included in the draft final report. This reviewer suggested that if the intent was to advance this technology to final deployment for ISB in offshore open water conditions, better algorithms to define burn area boundary edge must developed. This reviewer disagreed with the conclusion in

3. BSEE Study Report:

3.4–To demonstrate the technology proof of concept—What are the strengths or weaknesses of the methods used for the computations? Provide a rationale for each identified strength or weakness.

the draft final report that this study advanced the technology to TRL-5.[BL]

Another reviewer commented that weaknesses of this study's method included the lack of a more detailed procedure for calibrating sensors, calibrating thermal cameras, and more importantly, choosing a more strategic set of camera angles that would improve the accuracy of the computations (avoiding reflections and distortions). This reviewer recommended including in the final report the details about any such procedures that may have been used in this study. This reviewer commented again that another weakness in the draft final report was that it did not show computations or results over the series of 30 burn tests for the laboratory ISB experiments.[OG]

One reviewer commented that the burn volume computations were not clearly defined in the draft final report. This reviewer expressed concerns that incorrect measurement units were logged in Table 2 on page 28 of the draft final report (Section 2.3 Volume, Burn Rate and Burn Efficiency Measurements). This reviewer also stated that the accuracy of fire area calculation was not clearly defined with respect to normalizing areas where odd shapes of fire occurred during the laboratory ISB experiments. In addition, during the panel meeting this reviewer mentioned that interpreting the graphs in the draft final report was difficult because the draft final report did not provide enough information on the computations. This reviewer suggested it was important to include the formulas for how the oil volume was calculated.[NM]

Another reviewer commented that the formula used in this study for estimating ISB burn rate should be sufficient in a static laboratory setting; however, this reviewer qualified that comment by stating whether the formula was sufficient depended on having complete knowledge of the parameters (this was of significant concern; however, as this reviewer noted under Charge Question 1.5). The reviewer commented that this study's burn rate formula was developed for a closed system, where no oil was added.

This reviewer expressed concerns about applying this study's computation methods in an operational environment. The reviewer commented that this study's burn rate formula would no longer apply when ISB operations in offshore open water conditions had oil booming continue during ISB, because the rate of change of slick thickness would no longer provide a direct estimate of burn rate. For technology proof of concept for ISB in offshore open water conditions, the reviewer commented that the burn rate formula needed revision to quantify the amount of oil entering the ISB boom system and, presumably, the spatial variability of the oil slick thickness within the ISB boom system.[TW]

3. BSEE Study Report:

3.5–To demonstrate the technology proof of concept—Are there any other conclusions that could be drawn that are not adequately addressed in the report? Are there any other issues or concerns with the validity of the methodology or results that were not included in the previous charge questions?

The four reviewers addressed other issues or concerns with the validity of the methodology or results to demonstrate technology proof of concept based on their different areas of expertise. For this reason, the reviewers' comments for this charge question are summarized separately below. None of the reviewers addressed any other conclusions that could be drawn that are not adequately addressed in the draft final report.

Dr. Garcia-Pineda

Based on expertise with photogrammetric methods, one reviewer stated that the draft final report was properly structured, but emphasized that more technical details and results were necessary to provide a detailed description of the image processing algorithm. This reviewer stated that the draft final report needed to include analysis, comparison, and statistics for the multiple laboratory ISB experiments (30 burn tests) to demonstrate that this study's method was valid and could be repeated systematically.

This reviewer commented that addressing the reviewer's suggestions provided under the previous charge questions would add value to the work presented in draft final report and improve understanding of the laboratory experiment set-up. As an example, the reviewer commented again that the draft final report did not describe if the thermal imagery was calibrated with control points. The reviewer emphasized that thermal calibrated imagery should have more value for technology proof of concept. The reviewer noted that reflection from the water can be avoided by changing (increasing) the angle of the cameras. In addition, the reviewer suggested that using radiometric information (temperature instead of only emissivity contrast) could improve the results of the thermal imagery particularly if a higher angle is used to avoid reflections from the specular surface.[OG]

Dr. Lehr

Based on expertise with ISB in offshore open water conditions and photogrammetric methods, one reviewer evaluated whether the draft final report had made the case that this study's method offered a significant and consequential improvement over present methods, and concluded probably not. By consequential, this reviewer meant that the additional complexity of this study's method would be justified by achieving sufficient improvement in oil spill response estimates. The reviewer concluded that the draft final report as written did not make a solid case for such consequential improvement at this time, unless the reviewer's concerns discussed under the previous charge questions could be resolved.

This reviewer recognized that spill science is an applied profession and that conducting field work is never simple, and commended the researchers for their ingenuity in designing and performing this series of laboratory ISB experiments. The reviewer hoped that the researchers would accept

3. BSEE Study Report:

3.5–To demonstrate the technology proof of concept—Are there any other conclusions that could be drawn that are not adequately addressed in the report? Are there any other issues or concerns with the validity of the methodology or results that were not included in the previous charge questions?

any critical comments provided for the charge questions "in the spirit of constructive recommendations for what was a significant undertaking."[BL]

Mr. Mabile

Based on expertise with ISB in offshore open water conditions, one reviewer provided the following additional concerns specific to technology proof of concept for this study's research:

- Testing/calibrating acoustic slick thickness measurements through varying emulsions, ranging from 0-50%.
- Testing acoustic slick thickness measurements with realistic wave action inside an ISB boom system.
- Performing acoustic slick thickness measurements for more realistic conditions while towing an oil slick with an ISB boom system and with currents reflecting varying slick thicknesses contained within the ISB boom system.
- Integrating technology components in operational conditions with cameras for fire area calculations and slick thickness measurements.

This reviewer acknowledged that another big variable for technology proof of concept for measuring slick thickness is the emulsion factor; however, the reviewer understood that BSEE was already planning for future research studies with emulsions. The reviewer commented that ISB in offshore open water conditions will present many challenges. Acknowledging that this was a laboratory study, the reviewer commented that further study of acoustic measurement should evaluate slick thickness measurements through varying emulsion percentages (i.e., 10, 20, 30, 40, and 50%). The reviewer also noted that there would be varying emulsion percentages within a contained oil slick. Moreover, the reviewer suggested that varying emulsion percentages should be explored with respect to calibration of the acoustic measurement of slick thickness.

The reviewer stated that at around 50% emulsion of "water in oil," ISB ignition is not feasible, which has been confirmed in laboratories. This reviewer noted that during recent DWH ISB Team operations experience, the emulsion and weathering conditions prevented crews from accomplishing a sustained ignition on the fifth day after the final day of subsea oil release. From this reviewer's experience, ISB ignition does not occur after four to five days of weathering and emulsification at sea.

Also based on expertise with ISB in offshore open water conditions, this reviewer commented that other variables will be relevant—wind, wind vortexes, and the hot air draft principle—for ISB in offshore open water conditions. In addition, a large fire will have varying temperature profiles at different locations within the oil slick. ISB in offshore open water conditions will occur at a far distance from the source of the oil spill, so weathering and emulsification will occur, which will change the oil slick densities significantly. This reviewer commented that more research with

3. BSEE Study Report:
3.5–To demonstrate the technology proof of concept—Are there any other conclusions that could be drawn that are not adequately addressed in the report? Are there any other issues or concerns with the validity of the methodology or results that were not included in the previous charge questions?
emulsified oil was necessary to quantify the speed of sound in oil for ISB. Except for the case of accidental ignition, the reviewer noted that ISB will not usually occur with fresh oil near the source of an oil spill. ISB will typically get approved and deployed later in an oil spill incident, away from the source where weathering and wave action would create an emulsified slick. The reviewer commented that algorithms should be developed for this scenario along with methods for calibration to a range of percent (%) emulsification up to 50%.[NM] **Dr. Weber** Based on expertise as an acoustic measurement SME, one reviewer commented that the draft final report demonstrated what has been previously shown in the literature—sound waves reflect from oil/water and oil/gas interfaces, and if knowledge of the sound speed is available, these reflections can be used to determine a layer thickness. The reviewer commented that the researchers demonstrated an ability to make such acoustic measurements with a resolution of a mm, or perhaps a few mm. This reviewer stated that more advanced methods (e.g., broadband pulses) could likely be used to increase this resolution (this technique was employed by Bassett et al., JASA 137(1), EL32-EL38, 2015, who used lower-frequencies but broadband pulses). This reviewer suggested that such more advanced methods might be very useful for looking at oil slick and/or emulsion thickness when the oil temperature is constrained (i.e., not during an ISB).[TW]

4. PEER REVIEWER COMMENTS BY CHARGE QUESTION

This section provides the peer review comments of each reviewer, including each peer reviewer's general impressions, and the peer reviewer's final written peer review comments organized by charge question.

4.1 General Impressions

This section provides the peer reviewer's general impressions, including overall impressions addressing the accuracy of information presented, clarity of presentation, and soundness of conclusions.

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Dr. Oscar Garcia-Pineda

The work presented in this report is genuinely creative and innovative. This work is of high importance not only for the understanding of the burning rates during ISB on controlled settings but also because it offers the opportunity to evaluate this method on the cold weather environments as the CRREL lab.

The information presented in the report is objective and it shows with clarity the design of the experiment and the methods used for the analysis. I also think the report has some areas of improvement. Minimal misspellings were noticed.

I think as a technical report it is complete, however, if possible I would recommend to expand more on areas like:

- Repetition and verification of results (e.g., comparing times and rates over same amounts of oil volumes), in case this was done.
- Expand on the algorithm for the image processing.
- Expand on the image rectification technique.
- Include information about calibration of the camera setting, and the thickness measurements with the acoustic system.

I agree with the soundness of the conclusions because the results and importance of the test justify the relevance of this effort.

Dr. Bill Lehr

The project team has conducted a series of interesting experiments that utilize modern technology to improve on a traditional response tool, in-situ burning. The acoustic impedance approach to measure thickness is particularly exciting and should have application well beyond burning. The mapping of surface area by visual and IR cameras is more problematic and it is questionable to the reviewer that it offers sufficient improvement over traditional human eye methods to justify the increased complexity and likelihood of failure if used during the actual burn event. Burn regression rates have been extensively measured and found to be in a relatively narrow band for most oils. Burn times can be measured with a stopwatch. Most burns are over 90% efficient, giving a reliable number at the end of the burn of how much oil was disposed. This number

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generated by traditional means will be more accurate than other oil mass budget numbers such as volume dispersed or evaporated without going to the increased complexity suggested in this report.

Mr. Neré Mabile

First, it is truly exciting to know that research is moving forward in the area of automated burn rate and efficiency data gathering to in-turn, calculate a more accurate burn volume of oil removed. I am looking forward to transitioning from lab to the offshore "real world" with several challenges ahead.

<u>Information Presented</u>

My overall impression is that some good laboratory work has been done in testing and validating automated fire area estimations. I encourage more work in this direction. I did not agree with the claimed TRLs reported by the researchers in this report.

The lab work involving acoustical measurement for slick thickness was interesting, but not practical. In my opinion, applying real-time slick thickness measurement during offshore ISB is not practical and really not necessary. Acoustics measurement was tested with fresh oil only and ISB will involve emulsions most of the time. The burn rate study was a re-examination of the slick thickness while burning in pool fires, which was done many times before. Transition to "real world" would include studies on acoustically measuring oil emulsion thicknesses.

The dynamic, real-time volume calculations with burning different crude oils and studying slick thickness have been done before through NIST (Building and Fire Research Lab) and other commercial labs. There is even data from Russian field studies as far back as the 1950s. In my opinion, we know enough about burn rates (or the oil removal rates) with different crudes and emulsified crudes at varying thicknesses. Of course, the acoustic measuring device had to be proven. Although it is nice to have a re-confirmation on burn rates with different measuring devices while studying small pool fires. The burn rates reported correlates well with many other studies. The big challenge will be to measure instantaneous burn rates with a realistic offshore burn, much larger in size, with wave action, and varying oil/emulsion thicknesses contained within a towed boom system. Although, the report did mention the lack of wave action and current affects study.

From an operations perspective, I would encourage research more focused on figuring out a "practical" way to get a <u>reliable average value</u> of the emulsified and varying slick thicknesses within a burning slick towed by a fire boom system. And then, designing a practical fire area monitoring/measuring method for deploying in an offshore environment and typical conditions.

My general impression is that technology deployment feasibility studies should be done for real world application in order to steer research direction towards the highest potential for success.

From an operations perspective, the largest margin of error is the fire area estimation, because of

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the challenge in maintaining a good quality sustained surveillance. I hope to see more work focused with the application of photogrammetry and developing some reality solutions to determine how to successfully implement automated fire area monitoring from feasible platforms. For Burn Volume Estimation, the margin of error with burn rate and slick thickness assumptions are very small compared to estimating fire area on a constant, accurate and consistent basis.

Clarity and Accuracy

Based on the comments above, the TRLs (Technology Readiness Levels) were not appropriately referenced in the research report. I would say that a "Partial Simulation" was done.

The last paragraph in the report on page 7, states "Specifically, at the start of this project the ability to directly measure the volume of burning did not exist." This is inaccurate. As mentioned before, studies with NIST and other commercial labs accomplished this before.

Also it is unclear on the accuracy of the sound travel calibration through oil. The research report did not adequately explain how calibration was handled through different heat ranges with depth near the surface of the oil slick?

Calibration accuracy? In this report, there was an absence of measuring equipment accuracy or margin of error notation.

Soundness of Conclusions

The report concludes that this work created the capability to measure the instantaneous burn rate and efficiency during ISB. In the lab yes, but there are big steps to implement in reality. The conclusion should reflect the capability is in a lab environment with no waves, no emulsion with the total flexibility of placing cameras in ideal positions.

Dr. Tom Weber

The idea behind this work is that it is of critical importance to measure the amount of oil removed by in-situ burning (ISB), as well as to measure the efficiency of ISB (i.e., how much was burned compared to how much was left). ISBs can be dynamic, where oil booms are towed to capture additional oil after ignition, and so knowledge of a burn rate is an important aspect of quantifying the amount of oil removed. As described during the panel review for this work, ISB assessment methods used during the Deepwater Horizon oil spill involved estimating the area of the ignited portion of the ISB, multiplying this by a priori estimates of burn rate, and integrating over time to get a total number of barrels removed. Area estimates were conducted from visual inspection of the fire during overflights with a fixed-wing aircraft, using the boom as a size reference. Burn rates were taken from previous laboratory measurements (rates have been established for different burn types).

The present work seeks to improve on current methods for assessing ISB by measuring and monitoring the ignited slick area using IR and/or visible camera, and ignited slick thickness using

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upward-looking acoustic echo sounders.

The report is well-organized into sections that focus on the two basic measurement techniques, one for area and one for thickness, and on assessing these techniques in different scenarios (e.g., in the ice). However, the description of the work conducted often lacks the technical details required for a full technical review. There are some statements which are not self-evident and lack the literature references to support them. Several figures require color-scales or contours (or both) in order to more easily interpret them. Some of these issues are described within this review.

The methodology for assessing thickness appears to be flawed. One of these flaws is based on the premise that a measurement of thickness – or change in thickness over time - can be used to establish a burn rate. Such a burn rate could be established for a static environment, such as those tested in the reported laboratory work, but the description of ISB presented during the panel review was of a dynamic burn, where vessels towed the boom system (after ignition) to capture new oil to keep the burn going. This means that establishing a rate requires knowledge of how much is leaving the boomed slick (via burning, ignoring oil that slips under the booms as appears to sometimes happen) and how much oil is entering the boomed slick during towing. The present work only reports on thickness in the boom, and is this insufficient for determining a burn rate for the types of ISBs employed during the Deepwater Horizon response. This issue was not addressed in the report.

A second technical flaw was also unaddressed in the report. The measurement of thickness is inferred from a time-of-flight measurement of an acoustic pulse. Converting time to thickness requires knowledge of the temperature profile in the burning slick, noting that the speed of sound in oil changes by a few m/s per degree Celsius change in temperature and that the temperature change from the ignited portion of the slick to the ocean water is several 100's of degrees Celsius. Assuming that these temperature profiles are not constant throughout the burn (and they did not appear constant during the laboratory measurements), converting the acoustic time-of-flight measurements would require measurements of the temperature profile of the slick. Such a measurement of this profile includes knowledge of the location of both the top and bottom of the slick, and such knowledge would then obviate the need for the acoustic measurement in the first place. There are additional concerns about converting measurements of temperature to the speed of sound in an oil which has undergone some unknown amount of weathering and/or emulsification.

Measuring the area of an ignited portion of an ISB via camera seems much more feasible, particularly given that this is essentially what is done now. Replacing the subjectivity of human interpretation of area with an automated method seems a worthwhile endeavor.

4.2 Responses to Charge Questions

This section provides the final written peer review comments of each reviewer organized by charge question.

4.2.1 Quantification of Slick Thickness Charge Questions

1. Quantification of Slick Thickness:
1.1–Are the methods used to measure the oil slick thickness throughout the entire length of the *in-situ* burn tests valid? If yes, explain why these methods are valid. If not, how could the validity of the oil slick thickness measurement methods be improved or more clearly described?
Dr. Oscar Garcia-Pineda Maybe the experiment included a calibration test. I did not see much information about this in the report, and this could be an area for expanding on providing more details. I assume that maybe the acoustic system should have been tested under known variable thicknesses to validate that it was calibrated. It is mentioned in the report that a series of burns were made over a scale, it would be nice to see a comparison of results from different tests. One would expect to see the burning times and ratios not identical but well correlated if done under the same circumstances. It's difficult to think of a practical way to improve the experiment per se. Although there are other options to measure oil thicknesses in those ranges (1-12mm), one would have to interrupt the burning to proceed to take measurements. The whole experiment was designed to precisely monitor the sequence and gradient of the burning progression. So, interrupting the burning to measure thickness would be unpractical. Maybe just as a control/monitoring test to validate that the thickness measurements made by the acoustic method are within range. However, this might be out of the scope of the project.
Dr. Bill Lehr The research team uses acoustic impedance to measure oil thickness. The technique is unfamiliar to the reviewer but the physics appears to be straightforward. A comparison is made between a sonic pulse signal reflection from the oil-air interface and a weaker reflection from the oil-water interface. The dual transit time through the oil multiplied by the signal velocity in the oil medium gives thickness. Based upon Figure 12, the pulse has a duration ~ 2 microseconds, yielding, from the equation on page 17, a minimum measurable oil thickness by this method of around 1 mm. This should be sufficient for burn measurements since oil thinner than twice this would not sustain a burn. According to the supplemental material, oil temperature varies by several hundred degrees Celsius over the space of a few mm. Since the sound velocity through the oil depends on the spatially varying oil temperature, use of the method would seem to depend on being able to accurately measure this significant temperature change, or at least be able to correctly estimate it for varying oil types and thicknesses. Unfortunately, the latter is the exact unknown property that is to be calculated. Figure 13 shows that, once serious burning commences, the resolution of the thickness measurement diminishes, with the transit time measurement spread over about 5 microseconds. Once subsurface water boiling begins, the whole concept of an oil-water layer breaks down but

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this probably only applies to very shallow water circumstances. Open ocean water should have sufficient convection to provide a necessary heat sink. A separate question arises for oil that becomes, or begins to become, emulsified as the heat from the burn will break the emulsion and create local turbulence. It is the understanding of the reviewer that emulsions were outside the scope-of-work. A somewhat perplexing graph occurs in the supplemental material where the label is speed of sound versus time but the equation applies to sound speed as a function of temperature (fitted as a cubic). Details on this equation would have been useful.
Mr. Neré Mabile The methods described, I think are valid. In section 2.2.4, the data reflects the burn stopping when the measured slick thickness reached 2mm. This correlates very well with many laboratory test done in the past. At 2mm, the water acts as a heat sink and starves the fire of the required heat to vaporize crude oil at the surface of the slick. This has been the established thickness threshold where the oil insulative qualities are not enough to vaporize the oil to sustain combustion.
Dr. Tom Weber The thickness measurement requires the measurement of echoes from both the oil and air/water (or flame/water) interfaces and an estimate of the harmonic mean sound speed in the oil. The general “echo sounding” principle behind this approach is valid, and the report shows clear evidence of resolvable echoes from both interfaces. This in and of itself is not surprising, and similar work has been conducted in “static” environments where the oil is not ignited (see, for example, Bassett et al., JASA 137(1), EL32-EL38, 2015, who were measuring 40 mm thick layers of oil using broadband echo sounders operating between 200-300 kHz). The ignition of the oil in the present work raises some additional challenges, however, and it is not clear how these challenges will be overcome. The largest challenge with this method is related to converting travel time to distance, which requires knowledge of the sound speed profile through the oil layer. The sound speed in oil is a strong function of temperature, as shown in this report, varying by several hundreds of m/s over the temperature ranges relevant for burning oil (ocean temperatures to several hundred degC). Temperature profiles in the report show strong gradients – of the order of 100 degC per mm – with variations throughout the burning process. The acoustic travel time measurements would require knowledge of the harmonic mean sound speed through the oil in order to estimate the layer thickness. But knowledge of the harmonic mean sound speed requires a temperature profile, which in turn requires temperature sensors to be placed in the slick. Further, these temperature sensors have to be vertically referenced to the slick. The location of the top of the slick must be known, which seems challenging given the results provided in the report which do not show an easy path to discriminating between the upper portion of the ignited slick and the flame above it. Information provided with the report suggests that the laboratory method relied on a visual

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1.1–Are the methods used to measure the oil slick thickness throughout the entire length of the *in-situ* burn tests valid? If yes, explain why these methods are valid. If not, how could the validity of the oil slick thickness measurement methods be improved or more clearly described?
estimate for which temperature sensors were submerged, including a straight-line fit for the height of the slick as it burned off. Note that the acoustic measurements do not match a straight line fit, and so the temperature profiles used for this work represent only a crude estimate. The requirement for an accurate temperature profile takes away from the ease with which the acoustic measurement can be made, even in a laboratory setting. Remaining on the topic of converting travel time to distance, there is an important link between draft-report-Figure 13 (acoustic result) and draft-report-Figure 14 (temperature), although it is not clear whether these data are from the same experiment. According to Figure 5, the acoustic sensor and the thermocouples are fixed with respect to one another, and the 16 thermocouples are at fixed altitudes (not depths, as is described in the manuscript). Assuming that the highest thermocouple was at the top of the slick prior to the burn, as described in Figure 14, much of the temperature measurements are taken above the surface of the burning slick, presumably in the flame. That is, by approximately 200 seconds in Figure 14, about 7 mm of oil should have been burned according to Figure 19 and Figure 21. This suggests that the interpretation of Figure 15 is incorrect: these temperatures are partially from the air/flame (the top 4 mm of Figure 15-left, and four times greater than 175 seconds of Figure 15-right) and not all in the slick.

1. Quantification of Slick Thickness:
1.2–Is the method to quantify the speed of sound in oil during *in-situ* burning operations valid? If yes, explain why the method is valid. If not, how could the validity of the speed of sound in oil quantification method be improved or more clearly described?
Dr. Oscar Garcia-Pineda As far as I understand, I don’t know a better way (practical) to do it.
Dr. Bill Lehr The reviewer must admit to insufficient expertise to truly assess the method although no obvious scientific irregularities are present. Since the sound velocity through the oil depends on the spatially varying oil temperature, use of the method would seem to depend on being able to measure this significant temperature change, or at least be able to accurately estimate it for varying oil types and thicknesses. Unfortunately, the latter is the exact unknown property that is being sought. According to the supplemental material provided, determination of thermocouple location relative to the top of the slick was done by visual inspection. That hardly seems a valid approach for real burns. The supplemental material says that slick surface in relation to the thermocouples will in the future be determined by a non-linear function of time. The reviewer does not see how this solves the problem. An explanation is needed.

1. Quantification of Slick Thickness:
1.2–Is the method to quantify the speed of sound in oil during *in-situ* burning operations valid? If yes, explain why the method is valid. If not, how could the validity of the speed of sound in oil quantification method be improved or more clearly described?
Mr. Neré Mabile I'm not sure that the calibration is accurate and do not understand how calibration can be accomplished accurately when there is a variable heat range throughout the slick thickness under the burn or fire. The accuracy of measurement instruments used in quantifying the speed of sound was not portrayed.
Dr. Tom Weber The method for quantifying the speed of sound in oil – making measurements of travel time over a fixed distance as a function of temperature – is adequate for use in the laboratory experiments described in this report. The only limitation is the range of temperatures over which the sound speed has been measured, which do not extend to the high temperatures observed during the laboratory experiments. A polynomial fit was employed to extrapolate the speed of sound to higher temperatures, but the uncertainty of this fit was not established and presumably some unknown bias is retained in the final measurements of thickness. I would further note that the report authors require a reference for their statement that "the speed of sound in a fluid is directly related to the viscosity" made in the draft report. Sound speed is typically considered to be related to the bulk modulus and the density of the fluid, and independent of the viscosity.

1. Quantification of Slick Thickness:
1.3–Does the report adequately address the measurement of varying slick thickness throughout the entire slick? If yes, explain why this measurement is adequately addressed. If not, how could these measurements be improved or more clearly described?
Dr. Oscar Garcia-Pineda Yes. The distribution of the transducers is graphically explained. If there would be any variances on the slick inside the tank the transducers located in different places would record that variance.
Dr. Bill Lehr The report on page 53 notes that the project did not attempt to measure spatial variations in the slick, which is unfortunate because one of the most attractive features of this experiment is the capability to measure surface oil thickness at various locations. A practical tool operationally deployed during an actual spill incident could, along with modern remote sensing techniques, finally provide the "holy grail" of spill science, a trustworthy estimate of surface oil volume. Thick oil collected in booms that have an open end to the sea will show some small slope from front to back but the reviewer would be surprised if that small inclination interfered with local

1. Quantification of Slick Thickness:

1.3–Does the report adequately address the measurement of varying slick thickness throughout the entire slick? If yes, explain why this measurement is adequately addressed. If not, how could these measurements be improved or more clearly described?

thickness measurements by this approach if sufficient acoustic sensors with adequate focus (or a moving sensor with several measurements) were used to calculate the slope. What might be more problematic is spatially varying oil input to an open-ended burn area, causing some cross-sectional thickness differences at the mouth of the opening. During the final burn stages, certain areas will stop burning before others but most of the oil will have been consumed by then.

The report does not discuss unburned residue and how this could affect thickness and area measurements. It also does not discuss the degree of uncertainty expected from variations in water depth of the ROV, a length scale larger than the oil slick thickness. Presumably the system would automatically correct for this by the timing of the return signal from the oil-water interface but it would be nice to see the details.

As a general rule for projects of this nature, one would expect to find extensive tables of measurement results or, at minimum, error bars on the graphs such as Figure 19. Both are lacking in this report.

Mr. Neré Mabile

For this laboratory test, I think yes. But to improve these measurements, thicker slicks need to be studied and measured. This is relating to transition to offshore, actual conditions. A fire boom will create slicks up to 16” to 18” in depth right near the apex of the “U” shaped boom. Pulling fire boom at ½ to ¾ knot, will build up oil to a depth reaching the bottom of the boom skirt. The slick will vary in depth with a slight thickening at the leading edge of the boom with increasing thickness towards the apex. This dynamic slick thickness variation inside of a fire boom will depend on the type of oil, viscosity, gravity, speed of tow, fluid dynamics, drag coefficients, etc.

Page 23 of the report mentions and recognizes the fact that slick thickness for larger burns will vary in thickness.

Dr. Tom Weber

The report describes the use of up to eight acoustic transducers in the laboratory tests (Figure 5). The results of the measurements from these multiple transducers are not included in the report – only measurements from one transducer per burn are described. The one exception to this is the in-ice burns, where measurements from a single frame-mounted and a single ROV-mounted transducer are described, but with no “attempt to measure the spatial variations of the slick thickness” according to the draft report. So no, the report does not address the measurement of varying slick thickness throughout the entire slick.

Given the constrained laboratory setting of the experiments, it is not clear that the slick thickness should even vary during the burns. It would still be valuable, however, to explore the variations in the thickness measurements between the different sensors, with some attempt to partition the inevitable differences between actual changes in thickness and measurement uncertainty/bias.

1. Quantification of Slick Thickness:

1.4–Does the report adequately address how the methodology for acoustic slick thickness measurements would be affected by waves and currents in open water conditions? Explain any issues or concerns that might affect the validity of this acoustical methodology in open water conditions.

Dr. Oscar Garcia-Pineda

The report mentions the possibilities to operate the ROV from a vessel. It mentions that they are testing the acoustic slick thickness measurements within a range of conditions (harbor chop to 23 inches wave height). I think in this regard authors should provide more awareness of the limitations of the acoustic system. In my opinion the ability to operate a system like the ROV shown here would be extremely challenging beyond a strict range of sea state conditions. And it sounds like this is currently under investigation by the authors of this report. However, details about this topic are very limited in the report.

The acoustic precision is dependent on the alignment between the transducer and the surface. If turbulence is present, this might compromise the accuracy of the readings since the transducer is no longer perpendicular to the surface where oil is floating. Therefore, the oil layer dynamics will be changing its thickness constantly and maybe would not be captured properly by the sensor.

Dr. Bill Lehr

In general the acoustic thickness measurement method seems scientifically sound for non-burning oil under calm surface conditions. Comparison with direct oil mass measurements (Figure 22) supports this conclusion. The research team asserts on page 17 that they compare wave peak measurements when waves are present. Details on how this was achieved are missing from the report. The reviewer wonders if oscillating interfaces of different frequencies will increase spatial return signal scatter. The report on page 53 mentions other studies where slick thickness measurements were successful for wave heights of ~60 cm, greater than the freeboard of many booms used to contain the oil. The reviewer was not tasked to evaluate the report of these other studies but a cursory analysis indicates that the earlier report includes more measurement data results than this report. As a general rule for projects of this nature, one would expect to find extensive tables of measurement results or, at minimum, error bars on the graphs. Both are lacking here.

Constant currents should not be a problem for this method since such currents will, by necessity, be less than a knot for the fire booms to contain the oil. Varying currents may be problematic if one wishes to maintain a cohesive slick and not lose control of burning oil. During Deepwater Horizon (DWH), burning oil often escaped from the booms.

Mr. Neré Mabile

No, the report does not address this as mentioned within the text on page 53 at end of Section 4.2. Concerns that might affect the validity in open water, as mentioned before, would be the presence of emulsions (created by waves) affecting density and affecting calibration and measurement. The

1. Quantification of Slick Thickness:

1.4–Does the report adequately address how the methodology for acoustic slick thickness measurements would be affected by waves and currents in open water conditions? Explain any issues or concerns that might affect the validity of this acoustical methodology in open water conditions.

emulsification factor would also vary throughout the slick.

Also, from prior testing of small waves (5 and 10cm) in 1980 noted by Tam and Purves; the presence of waves reduced the burning rates by increasing the heat transfer to the underlying water. Buist and McAllister (1981) reported reduced burn times at constant tow speeds with increasing regular wave heights, but no decrease in visible combustion intensity. The latter test was done at the Ohmsett test facility. Buist and McAllister (1981) also noted that the effects of currents on ISB burning rates are negligible.

Ref: Tam, W.K. and W. F. Purves. 1980. Experimental evaluation of oil spill combustion promoters. Proceedings of the Oceans '80 International Forum on Ocean Engineering in the 80s. IEEE, Piscataway, NJ. pp. 415-422.

Ref: Buist, I.A. and I.R. McAllister. 1981. Dome Petroleum's fireproof boom --- development and testing to date. Proceedings of the Fourth Arctic and Marine Oil Spill Program Technical Seminar, June 16-18, Edmonton, Alberta. Environment Canada, Ottawa, Ontario. pp. 479-497.

Dr. Tom Weber

This is not addressed in the report.

Waves and currents could potentially create emulsions of oil and water, or gas bubbles, which could lead to increased volume reverberation below the slick and confound the detection of the interfaces. The methodology for detecting the interfaces relies on identifying the same cycle of the reflected waves for different interfaces, and volume reverberation could make this unreliable. Other approaches that rely on match filtering and/or the signal amplitude envelope may be more robust.

Waves and currents could also hinder the safe-operation of placing an ROV underneath the surface of burning oil.

1. Quantification of Slick Thickness:

1.5–Are the assumptions of the oil thickness algorithm input clearly defined and appropriate (see Sections 2.2.4, 3.1.3, and 3.2.3)? If yes, explain why. If not, explain how those assumptions could be defined more clearly. Provide a rationale for your answer about the appropriateness of the assumptions of the oil thickness algorithm input.

Dr. Oscar Garcia-Pineda

The description of the oil thickness algorithm is limited. I recommend authors expand on the

1. Quantification of Slick Thickness:

1.5–Are the assumptions of the oil thickness algorithm input clearly defined and appropriate (see Sections 2.2.4, 3.1.3, and 3.2.3)? If yes, explain why. If not, explain how those assumptions could be defined more clearly. Provide a rationale for your answer about the appropriateness of the assumptions of the oil thickness algorithm input.

technical approach and details about the algorithm inputs and handling of the variables.

Dr. Bill Lehr

The reviewer finds no problems with the algorithm assumptions in the report provided the limitations and expected error ranges are included, something missing from the draft report. All field measurements have limits on their validity and should have known expected accuracy. The reviewer searched in vain for serious derivation of the method and its range of application. One obvious question is the degree of horizontal spatial averaging by this method, assuming that the return signal is not giving a specific point reading from the returning sonar. This could be a problem if this method is extended beyond the test case of pure fresh oil to real spills where there may be large variations in degree of weathering for different oil patches that are collected in the same burn operation.

Mr. Neré Mabile

This is not my area of expertise.

Dr. Tom Weber

The measurement algorithm itself is rather simple – the thickness is defined to be the time difference of arrival for the two interface returns, multiplied by the sound speed and divided by 2. It does not appear that there is an invalid assumption in the formulation that would cause a problem for this method, but rather that some of these parameters (sound speed) are difficult to know, as described above.

There are some gaps in the description for the draft report that make assessing assumptions difficult. In section 2, for example, there is no mention of how the temperature was used to convert to sound speed. Was a harmonic mean used? Given that the thermocouples were fixed in place, how was the top of the slick determined for the temperature measurements (which were in turn required to calculate sound speed)?

1. Quantification of Slick Thickness:

1.6–What are the strengths and weaknesses of the slick thickness determination methods? Provide a rationale for each identified strength or weakness.

Dr. Oscar Garcia-Pineda

I think the most valuable strength is the fact that authors have made it possible at least under the controlled setting shown here. This has the potential to carry out more elaborated testing to understand many other things. Maybe they can create a lab setting to test oil burning rates under

1. Quantification of Slick Thickness:
1.6–What are the strengths and weaknesses of the slick thickness determination methods? Provide a rationale for each identified strength or weakness.
different levels of emulsifications, etc. More science can be done by just the fact that a measuring tool has been created. The weakest element on this chain is (as always) the limitations faced for testing on real setting environments. I do aerial mapping of oil spills for living. Observing moving oil is a challenging sport. The success of tactical operations at sea requires the control of many variables that only occur under a limited window of sea state conditions. Operationally speaking, I think the main challenge is the synchronization of the sufficient aerial photography needed (and the proper geo-rectification), but, certainly should be possible. That would need to happen with the proper deployment of the acoustic thickness system that should collect measurements under an array of points under the booming area, also could be possible under specific range of sea state conditions.
Dr. Bill Lehr It seems likely that the use of acoustic sensors could be included in some AUV or placed on the boom skirt to relay data to the response team prior to the burn. As Figure 13 illustrates, the acoustic method becomes less reliable once significant burning begins. Based on the figure, the reviewer speculates that errors of 50% are possible. Of course, once boil over begins, thickness becomes undefinable. Neither of these factors need be a drawback to this method in actual burn response. Boil over is a function of the artifice of experiments done in shallow confined pans. In open ocean conditions experiments show that subsurface water circulation prevents a dramatic increase in water temperature (e.g. the NIST mesoscale experiments in 1993). Also, as illustrated with this report (Table 1) and past published reports, there is a relatively constant burn rate for most of the burn with a gentle falloff as the thickness goes from 10 mm to the burn limit of ~2 mm. The reviewer excludes the burning during boil over where the greater exposed surface area temporarily (and artificially) increases the burn rate. Burn rate is usually considered to be relatively independent of oil type. Nevertheless, ASTM F-1788 publishes these minor variations that do depend upon the specific oil. Burn area and duration determines oil volume consumed by fire or transformed into unburned smoke particles (the latter probably about 10% of the oil mass), giving little value to thickness measurements during the actual burn. However, such measurements might be useful, depending upon the particular operation configuration, in providing an estimate of new oil volume captured as a redundant check on volume burned. One issue not addressed in the report in Section 4 (transitioning towards operational environments) is the matter of hazardous conditions during a large-scale burn. The report mentions that some practice was needed to develop the skill to negotiate the ROV under the burn for the small-scale experiments that were performed. Apparently, some equipment was damaged during the experiments. Large burns are much more dangerous to both personnel and equipment with significantly greater demand on both. Safety especially has to be a major consideration in any new

1. Quantification of Slick Thickness:

1.6–What are the strengths and weaknesses of the slick thickness determination methods? Provide a rationale for each identified strength or weakness.

modification to spill cleanup. The report should describe the expected training and precautions to allow this technique to be successfully done with minimum risk to operators and low potential for equipment damage.

Mr. Neré Mabile

The weakness are:

- The thickness is measured only at the point in the slick of each of the transducer probes and does not represent the entire profile of the slick.
- The calibration of sound transducers is difficult with varying temperatures within the slick during ISB.
- Emulsification variability will be a real challenge for sound calibration, which was not included in this research.
- From an operational perspective it is not easily envisioned how transducer probes could be deployed to provide useful information during an offshore ISB. I envision a netting structure suspended below a fire boom with fixed transducers. Floating debris would be a problem. ROV deployment would be very expensive and not practical to cover several burns at the same time.

Dr. Tom Weber

The strength of the method is the simplicity with which measurements of the travel time for echoes can be made. This methodology has been proven in a variety of settings, including for layers of oil, as has been reported in the literature.

The main weakness of the method is the requirement to measure in-situ temperature over very fine scales, vertically referenced to the slick, so as to convert the measurements of travel time to distance. Knowledge of the location of the top of the slick, which is required to generate a temperature profile, seems particularly difficult. Given the straight-line-fit approach to the upper interface of the slick reported by the report authors in response to follow-up questions on the draft-report, the issue of determining valid temperature profiles for the laboratory experiments remains unaddressed.

A second weakness is the requirement for knowledge of the temperature-dependent sound speed of oils, which could only be measured over a finite range of temperatures, and must be made for each type of oil (or oil/water emulsion) used.

4.2.2 Quantification of Slick Area Charge Questions

2. Quantification of Slick Area:
2.1–Are the methods used to measure the surface area of the burning slick valid? If yes, explain why these methods are valid. If not, how could the validity of the area measurement methods be improved or more clearly described?
Dr. Oscar Garcia-Pineda Yes. The experiment is based on the known geometry of the tank, and on a real setting environment, the operators of this system by knowing the length of the booming, they can deduct the area for measurement under ISB.
Dr. Bill Lehr The reviewer presumes that one purpose of this project was to do proof of concept to see if this approach could be advanced up the TRL level to full operation. If that is the case, then the burn area measurement methods should be scalable to real field burns. In DWH, that required observers in aircraft. This project used multiple cameras taking simultaneous images. That does not seem practical with aircraft. The study team meets the distortion challenge by using planar homography, a well-established technique to adjust different images to a common reference plane with a common length scale. This technique normally uses reference points to define that common plane. The reference points (or other points at known location from these points) should be observable by all, or most, of the cameras. The report on page 42 claims that two cameras at opposite ends of the burn are sufficient to eliminate false positive readings and smoke obscuration. This seems surprising to the reviewer. Unfortunately, the necessary documentation to check this claim is missing from the report. The reviewer anticipates that surface mapping of the burn area will always present challenges in real burns.
Mr. Neré Mabile Yes, it appears that the methods presented are valid and part of existing technology frequently used for other applications. An improvement would be to also test in darkness application. Offshore burning could extend into the night and this was the case a few times during the DWH response. The challenge to real world transition will be to design procedure/methodology to maintain constant and sustained fire area monitoring (in daylight and darkness) to capture an accurate burn volume. The fire area is the most important and most significant value to the volume equation that is usually hard to acquire. Burn rate can be estimated, burn duration is easy to obtain and record, but fire area accuracy is most challenging.

2. Quantification of Slick Area:

2.1–Are the methods used to measure the surface area of the burning slick valid? If yes, explain why these methods are valid. If not, how could the validity of the area measurement methods be improved or more clearly described?

Dr. Tom Weber

The report describes the use of cameras from multiple angles to measure the surface area of the burning slick. This seems technically possible, and the report shows believable results. However, the description of the method is not clearly described. There is no description of what ancillary inputs are required to perform planar homography (presumably altitude and orientation?), so that these requirements could be considered in the context of an at-sea operation.

Information regarding how the presence or absence of fire is detected is inadequate. Information provided subsequent to the draft report suggests that a simple threshold was used to detect pixels containing fire, but potential difficulties related to lighting conditions, water surface reflections, or other potentially confounding issues were not addressed in the report.

2. Quantification of Slick Area:

2.2–Are the numbers of images, heights, and angles from around the fire adequate for accurate area computations using the photogrammetric methods reported? Explain how the approach chosen could affect the validity of the methodology and results.

Dr. Oscar Garcia-Pineda

The report provides a lot of details about the technical setup and connectivity for the cameras. The reader ends up with a general idea of how the rectification is achieved. However, as indicated on previous questions, I think more details about the setting should be included. A sketch describing the range of heights, distances, angles, would be very illustrative.

Is the algorithm capable of handling images collected at different heights and angles? It would be interesting to see if authors achieved similar burning rate results by placing the cameras under different viewing geometry. I can imagine (with my experience as UAS operator) that one can achieve sufficient aerial views of the ISB on a single flight. However, in practice I would struggle to fly my UAS at fixed altitude and a fixed distance from the ISB. Maybe the algorithm can handle views from different angles and distances.

The report states that a number of tests (about 30 burns) were conducted, but the report does not include results on each of those tests. It would improve the understanding of the limitations and merits of the whole approach to see when it does well, when it does not. By having conducted all those tests, authors should provide information about the variables. I don’t think is expected that all those burns happened exactly the same; therefore, showing the repeatability of the experiments would be valuable and would reinforce the understanding of the results.

A sketch of the distribution of the cameras (distances, angles, etc.) would help to understand if

2. Quantification of Slick Area:

2.2–Are the numbers of images, heights, and angles from around the fire adequate for accurate area computations using the photogrammetric methods reported? Explain how the approach chosen could affect the validity of the methodology and results.

there was an optimal set of geometric conditions to obtain the best results.

Dr. Bill Lehr

It seems that camera number and placement was adequate for the small test burns. The reviewer is curious as to the planned placement of cameras during actual open water burns. Is the concept to put them on support vessels or deploy them on their own floating or airborne platforms? Given the need to maintain a significant safety distance from the burn itself and the impracticality of high mountings of the cameras on their own platforms, it would seem that the view angles could be unfavorable, magnifying the distortion problem. Ideally, the view angle should be less than 30 degrees from the vertical. The project team, in answer to Panel questions, states that their method works for angles as large as 65 degrees.

IPIECA recommends a "safe" downwind distance for a thousand square meter in-situ burn as 1 km, a considerable distance from the fire. The report states that distant cameras and lower resolution (150x150 over fire area) provide sufficient accuracy. Unfortunately the calculations used to justify this statement are not included in the report.

Mr. Neré Mabile

Not my expertise, but I think the characteristics of the data gathering are adequate.

The approach heights and angles might be different if dealing with very large fires where there is oxygen starvation in the center creating low burn efficiency, resulting in very dark black smoke. With high winds, the smoke plume could lay down and cause potential obstructions.

Dr. Tom Weber

The report demonstrates believable results with three images, so perhaps this is sufficient. The report does not describe any efforts to examine how the results change as a function of the number of images, or their locations. Given that there were more than three images used, it is possible to at least begin such an investigation. A fuller analysis that examines changes with number of images, height of images, and angles of images would be desirable.

2. Quantification of Slick Area:

2.3–Does the report adequately address the methods to account for errors from obstructions and limited angles/heights/distances? Explain how the methods used to account for errors could affect the validity or scientific merit of the methodology and results.

Dr. Oscar Garcia-Pineda

The account for errors from obstruction was briefly covered. The report mentions the causes for

2. Quantification of Slick Area:

2.3–Does the report adequately address the methods to account for errors from obstructions and limited angles/heights/distances? Explain how the methods used to account for errors could affect the validity or scientific merit of the methodology and results.

obstructions and how these challenges can be addressed. However, more details about the account for errors could be included.

The approach used by authors sets a good start, in the future I would recommend to use a moving platform (i.e., a UAS) flying at an equidistance from the center of the burning area (and at different heights). This would provide a 3D (volumetric) perspective and other things can be captured (i.e., density of the smoke plume) that can aid in the calculation of the burning.

Dr. Bill Lehr

For operational burns, obstruction from the booms or other equipment would be relatively small compared to the boomed area. While not a problem for these small-scale burns discussed in the report, NIST reported 10-15% of the mass of the oil converted into smoke particles for large-scale open water burns. At best, the method might be able to estimate the smoke area for a real response burn in open water. As the report notes on page 42, smoke area may be indistinguishable from, or obscuring of, fire area, even in the IR range. The project team suggests that multiple cameras and dynamic phasing of the imagery can overcome the “false positive” burn area by looking at the flame from different angles at different times. The report also states that flame may be separated from smoke by using a different IR frequency band. This may be the case. However, the smoke area can be at different temperatures, encompass the entire smaller burn area and/or change location due to wind fluctuation, making image analysis, and camera placement and timing, problematic. For example, films of the DWH burns show flame appearing well above the water surface and surrounded by smoke.

Mr. Neré Mabile

This is not my area of expertise, but the methodology seems to account for errors of obstruction.

One point, if conducting an ISB with high winds, the smoke plume lays down a lot and black and gray smoke might affect the validity and might account for error.

I can’t help but think about transition to “real world” where burns can last 12 hours or more. This technology is not new, but applying this constant fire area monitoring to large offshore burns 200 or 300 feet in diameter would be new.

Dr. Tom Weber

The issue with occlusion due to obstructions appears to be adequately solved with images from multiple angles around the fire. A greater issue seems to be dealing with smoke, which the report describes as being problematic for both the visual and infrared cameras. Examining the photographs of ISBs shown in Figure 1 of the report, the challenge would appear to be billowing smoke when wind is present (see the third panel of Figure 1). The billowing smoke issue would appear to be a difficult problem to overcome using the present methods. A greater investigation of

2. Quantification of Slick Area:
2.3–Does the report adequately address the methods to account for errors from obstructions and limited angles/heights/distances? Explain how the methods used to account for errors could affect the validity or scientific merit of the methodology and results.
the use of IR – perhaps one that identifies a specific IR wavelength – seems warranted.

2. Quantification of Slick Area:
2.4–Are the assumptions of the area algorithm input with respect to burning area of the slick clearly defined and appropriate (see Sections 2.1.1, 3.1.1, and 3.2.1)? If yes, explain why. If not, explain how those assumptions could be defined more clearly. Provide a rationale for your answer about the appropriateness of the assumptions of the area algorithm input with respect to burning area of the slick.
Dr. Oscar Garcia-Pineda Yes. Because the area of the ISB will be known by the length of the booming. A summary of results obtained from different tests would help to validate the algorithm performance. However, the report did not include results from different burns or a comparison of the performance from different times.
Dr. Bill Lehr The burn area is observed from multiple cameras, each with a unique view angle, and perhaps in a real incident, elevation. The study team meets the subsequent distortion challenge by using planar homography, a well-established technique to adjust different images to a common reference plane with a common length scale (the water surface and burn area limits). This technique normally uses reference points to define that common plane. The reference points (or other points at known location from these points) should be observable by all, or most, of the cameras. The study should clarify how the method ensures that this is the case when smoke may obscure the images, or alternatively, the number of cameras with clear view that are sufficient for the accuracy of the area measurement by this method if some are obscured. The report hints at two but that seems too few to the reviewer. The report notes on page 40 that the results of 30 burns can be used to empirically determine error and verify the limits of forming an accurate homography but does not provide those results so it is difficult to know if the errors are within an acceptable range. In answer to Panel questions, the project team noted that only single RGB pixel results were used define flame on the water surface. The algorithm in their reply seems woefully inadequate to the reviewer. At minimum, adjustments need to be made to define flame only on the water-oil surface plane as opposed to flame in planes above the water surface. Rules should be based at least on differences with surrounding pixels, not the absolute readings of any individual pixel. Better IR will probably be required. In the reviewer's judgment, this is one of the most important gaps in the report if the plan is to move up the TRL ladder.

2. Quantification of Slick Area:
2.4–Are the assumptions of the area algorithm input with respect to burning area of the slick clearly defined and appropriate (see Sections 2.1.1, 3.1.1, and 3.2.1)? If yes, explain why. If not, explain how those assumptions could be defined more clearly. Provide a rationale for your answer about the appropriateness of the assumptions of the area algorithm input with respect to burning area of the slick.
Mr. Neré Mabile Not my area of expertise. But, it is noticeable that the fire area demonstration photos on page 15 of the report seem to show some normalizing of areas where the odd shapes of fire occur. The margin of error or accuracy is not clearly defined. What pixel resolution is used and how much estimation or "rounding off" is being done with these odd fire shapes? Large burns will have many of these odd shapes and edges throughout the burn.
Dr. Tom Weber It is difficult to answer this question without more detailed knowledge about the fire detection algorithm (step 6 above section 2.2) or examples of how an external length scale such as a boom are used to quantify the area (step 8 above section 2.2).

2. Quantification of Slick Area:
2.5–What are the strengths and weaknesses of the methods for the determination of the area(s) of the burning slick? Provide a rationale for each identified strength or weakness.
Dr. Oscar Garcia-Pineda The area of the ISB can be accurately calculated with aerial view and with references from the positions of the vessels. However, the report does not address how the algorithm or the authors plan to address the calculation of the area of a burning slick. There is no mention to the usage of dynamic control points and how they will be incorporated on the mapping (area calculation algorithm). Control points on the open field are a must. If this approach is intended to be taken to the next steps, I would recommend to try much higher altitudes for capturing the tests. Oblique imagery and such low angles (as shown in the report) can cause more specular reflections and distortions that complicate the image processing and would result in inaccurate results. This problem can be solved if higher altitudes for capturing the photography are used. Again, a UAS with thermal and high resolution RGB could help to minimize this problem.
Dr. Bill Lehr The most significant challenge that burn area measurement by visual and IR recording would face

2. Quantification of Slick Area:

2.5–What are the strengths and weaknesses of the methods for the determination of the area(s) of the burning slick? Provide a rationale for each identified strength or weakness.

in an operational application would be obscuring of the burn area by produced smoke. While not a problem for the small-scale burns discussed in the report, NIST reported 10-15% of the mass of the oil converted into smoke particles for large-scale open water burns. At best, the proposed method might be able to estimate the smoke area for a real response burn in open water. As the report notes on page 42, smoke area may be indistinguishable from, or obscuring of, fire area, even in the IR range. The project team suggests that multiple cameras and dynamic phasing of the imagery can overcome the "false positive" burn area by looking at the flame from different angles at different times. The report also states that flame may be separated from smoke by using a different IR frequency band. This may be the case. However, the smoke area can be at different temperatures, encompass the entire smaller burn area and/or change location due to wind fluctuation, making image analysis, and camera placement and timing, problematic. For example, films of the DWH burns show flame appearing well above the water surface and surrounded by smoke.

This may be much less of a problem from smoke from small contained burns such as the CRREL ice burns but then burn area is more constrained to begin with. Multiple cameras seem useful in cases where the flame can be clearly distinguished from the smoke for at least one view, allowing correction for such artifacts as flame reflection from the water surface.

Mr. Neré Mabile

The strengths are: using automated equipment to "tirelessly" and more accurately perform the fire area estimation.

The weaknesses include unclear definition of the margin of error or accuracy. The "rounding" of areas were done, but not clearly defined how.

Dr. Tom Weber

The main strength of the approach is the simplicity of the measurement – camera images are routinely collected using manned aircraft and drones at sea, they have been used previously to measure the sizes of objects, and it seems that this technology could be readily applied to the problem of ISBs.

The main weakness seems to be obscuring of the burn area by blowing, billowing smoke, as can be seen in some of the example ISBs shown in the introduction. Cameras can't measure what they can't see and, according to the report, this issue is present even for cameras operating at infrared wavelengths. If present, billowing smoke could cause large biases in the estimates of area. These seem to be solvable problems, but remain largely unaddressed in the draft report.

4.2.3 BSEE Study Report Charge Questions

3. BSEE Study Report:
3.1–To demonstrate the technology proof of concept—Does the report adequately address the methodology to accurately calculate the volume of the entire slick given the differences in thicknesses throughout the entire slick being burned? Explain how this affects the validity or scientific merit of the methodology and results.
Dr. Oscar Garcia-Pineda The report lacks on showing results obtained during multiple experiments (repetition). About how this affects the validity, there is a problem if the authors don't show how the performance of the system was measured during repeated trials. If the system works, then authors should be able to demonstrate that the experiment obtained similar results during different tests (or within reasonable variability). They mentioned they performed tests over 30+ times. It would be good to see the variability within those trials. When it works? When it doesn't? What are the main controlled / un-controlled variables, that is not shown and that is a requirement to understand the validation of results.
Dr. Bill Lehr The reviewer was uncertain when more than one transducer was used in any of the experiments. Presumably, more than one unit that are each spatially separated, or a moving unit that transits the burn area would provide spatially varying thickness measurements, given that the acoustic signal in each case was sufficiently focused. As noted on page 52, the project did not attempt to measure spatial variations of thickness so it is not possible to address methodology for spatial thickness variation from the report.
Mr. Neré Mabile No, it really does not. In Table 2 in the report section 2.3, The volume is reported in units of area in square centimeters. The volume calculation should have been the root of this report and explained more thoroughly.
Dr. Tom Weber There are gaps in the methodology that need to be addressed for making these measurements in a laboratory setting. In terms of the acoustically-derived thickness measurement, the measurement of the temperature profile of the oil needs to be refined. Of particular importance is determining the height of the upper layer of the oil (that is, the location of the oil/flame interface). This seems to be done only visually at the present time, and the results are not self-consistent (the time-varying height of the oil/flame interface used to generate the temperature profiles does not match the acoustic thickness measurement). A methodology needs to be established for doing this with greater accuracy, and an uncertainty for this methodology needs to be established. The issue of determining a temperature profile is compounded by the potential for spatial variability in slick thickness. This was unaddressed in the laboratory setting, although it appears

3. BSEE Study Report:
3.1–To demonstrate the technology proof of concept—Does the report adequately address the methodology to accurately calculate the volume of the entire slick given the differences in thicknesses throughout the entire slick being burned? Explain how this affects the validity or scientific merit of the methodology and results.
that the experimental setup would lend itself to such an investigation. To advance this method beyond a laboratory setting would require deploying sensors under the slick, in the case of the acoustic measurement, or in the slick to determine the temperature profile. The latter leads to an apparent basic flaw in the measurement: measuring the temperature profile requires knowledge of the slick boundaries (or at least the upper boundary), which implies that the slick thickness may be known before the acoustic measurement is performed. That there is no currently accepted method for making such a temperature profile measurement is certainly a limitation on the proposed acoustic methodology described in the draft report. Given the way in which oil is boomed to facilitate burning, it seems very likely that there will be large spatial variations in slick thickness. Operationally, the acoustic and temperature sensors would have to be deployed on an underwater vehicle – presumably an ROV or an AUV. This has not been addressed in the report, but likely would present a large operational challenge given the difficulties in deploying such sensors under the ocean under quiescent conditions. The high acoustic frequencies used in the proposed methodology would require very short range measurement (several meters, presumably), which places a vehicle only a few meters underneath an ignited burn. This would seem to create significant risk to the vehicle, its tether, etc.

3. BSEE Study Report:
3.2–To demonstrate the technology proof of concept—Does the report describe with reasonable accuracy how burn volumes, burn rates, and burn efficiencies are computed? If yes, explain why these computations are described with reasonable accuracy. If not, how could the report describe these computations more clearly or with improved accuracy?
Dr. Oscar Garcia-Pineda No, accuracy is not properly shown because there are not results shown for performance from repeated experiments. The report can be improved if analysis of performance over a series of burns is shown. When using the thermal sensors, it is important to always have reference points with known temperatures, that way, when the thermal image is obtained then it can be corrected for any thermal emissivity offsets. There are no thermal control points shown and no calibration description of the thermal camera in the report.
Dr. Bill Lehr The calculations of burn volumes, rates, and efficiencies are simple and straightforward.

3. BSEE Study Report:

3.2–To demonstrate the technology proof of concept—Does the report describe with reasonable accuracy how burn volumes, burn rates, and burn efficiencies are computed? If yes, explain why these computations are described with reasonable accuracy. If not, how could the report describe these computations more clearly or with improved accuracy?

Unfortunately, it is not possible from the report to truly assess the necessary accuracy of these numbers since no measurements come with error bars. The report would be more clear if it were to include information on the actual values used, and expected uncertainties in these parameters in their calculations. For example, the material discussed on pages 26-28 is confusing to the reviewer. The report shows some differences between burn rate as measured by mass (volume) loss and burn rate as calculated by thickness change. Is the difference simply due to water loss in the mass (volume) calculation? The bottom of Figure 25 indicates that the burn rate decreased significantly for thickness from 6 to 10 mm. This strange result contradicts the Buist et. al. study in Table 1 above the graph. One would expect that increased oil thickness would act as insulation, reducing heat loss to the water and producing higher burn rate. The reviewer assumes that the anomalous results in the graph are due to lack of steady burning early on, when the oil thickness was high, combined later on with the beginning of boil over. If so, the report should say this.

[editorial note –Table 2, Volume is not measured in cm2]

Mr. Neré Mabile

The report could describe the computation results better….. If the graph in Figure 23, Section 2.3; would depict the Y-axis "label" and "units."

Dr. Tom Weber

Determining the accuracy of these measurements in the lab requires a valid benchmark. The benchmarking has been inadequately described in this report. The benchmark used relies on converting the mass of the oil to its volume, and dividing the volume by the cross-sectional area of the burn container. The conversion of mass to volume requires the density, which is a function of temperature, and as shown the temperature is not constant throughout the oil layer. The report also quotes a density-temperature relationship, which is unreferenced. The report does not describe how the spatially (at least vertically) varying and time-varying temperature of the oil was used to find a density.

Beyond benchmarking in the lab, extension of this methodology to the field would require an uncertainty analysis (e.g., propagation of error) on the methods. This has not been undertaken, nor are there any estimates of the uncertainty in the individual components (e.g., arrival time, sound speed, pixel flame detection).

3. BSEE Study Report:
3.3–To demonstrate the technology proof of concept—Are the limitations and uncertainties clearly identified and adequately characterized for the determination of burn volumes, burn rates, and burn efficiencies? If yes, explain why. If not, how could the limitations and uncertainties for the determination of burn volumes, burn rates, and burn efficiencies be described more clearly or characterized with improved accuracy?
Dr. Oscar Garcia-Pineda Uncertainties and limitations are not clearly identified. It is necessary to include the analysis of performance under a number of trials.
Dr. Bill Lehr The short answer to this question is no. There are, for example, no error bars on any of the graphs. The report claims that there were 30 burn experiments that can be used to empirically determine error but the data and calculations are not included. For example, burn rate calculation accuracy versus peak wave height would be a useful chart, as would a graph of area estimate uncertainty as a function of average view angle. This lack of data result reports seems to be an obvious oversight for what would otherwise be considered a good research exercise.
Mr. Neré Mabile Burn rates and efficiencies were characterized adequately and the results correlated well with many previous studies done in previous laboratories. Burn volume was not clearly or adequately characterized.
Dr. Tom Weber No, the report does not adequately describe or identify the limitations and potential pitfalls of the proposed methodology. The most fundamental limitation for extending this method to a field environment is dynamic nature of ISBs, as discussed during the panel review with ISB experts, where oil is entering the boom as it is towed. Two factors will change the thickness: the amount entering and the amount being burned off; but only one factor affects the burn rate: the amount being burned off. Thus, measuring the thickness alone without knowledge of the amount entering is insufficient for estimating the burn rate. Another fundamental limitation is the need for knowledge of the sound speed of the oil. This requires knowledge of the oil temperature profile, for which there is no established method in the field, but it also requires knowledge of the temperature-dependent sound speed. Current methods for establishing this sound speed require empirical testing with oil samples. How this can be done for oil that has been weathered at the surface, or turned into an emulsion, is unclear and has not been addressed in the report.

3. BSEE Study Report:

3.4–To demonstrate the technology proof of concept—What are the strengths or weaknesses of the methods used for the computations? Provide a rationale for each identified strength or weakness.

Dr. Oscar Garcia-Pineda

Computations make sense as presented. This is based on basic arithmetic computations based on the observations of the burn rate, thickness change, etc.

The strength of the method is the approach itself. It is a genuine great effort put together by the authors and it represents a strong foundation for further development of science.

About the weaknesses of the method, I would recommend to incorporate a more detailed procedure for calibrating sensors, thermal cameras, and more importantly choosing a more strategic set of angles that would improve the accuracy of the computations (avoiding reflections and distortions).

Another weakness in the report is that it does not show computations (or results) over several trials.

Dr. Bill Lehr

The strength in the calculations used in the report is that they are simple and easily understood. This is important when explaining results during a spill emergency to non-technical decision makers. While the report establishes proof of concept for measuring thickness during the burn, it does not give a rationale for substituting well-documented burn rates for something calculated on the fly during an emergency operation. Moreover, some of the more complex calculations such as signal to noise ratio from the acoustic measurements and view correction uncertainty using planar homography are not included so it is difficult to evaluate method accuracy. If the intent is to advance this technology to final deployment, better algorithms to define burn area boundary edge need to be developed. The reviewer disagrees with the report conclusion that the work advanced the technology to TRL 5.

Mr. Neré Mabile

Volume computations were not clearly defined. Wrong units were logged in Table 2 of the report section 2.3. The accuracy of fire area calculation was not clearly defined as far as the area normalizing.

Dr. Tom Weber

In a static laboratory setting, the formula used for estimating ISB burn rate should be sufficient, as long as complete knowledge of the parameters can be had (this is of significant concern, however, as noted above). This formulation is for a closed system, where no oil is added. In an operational environment, where oil booming continues during burning, the formulation no longer applies and the rate of change of thickness no longer becomes a direct estimate of burn rate. The formulation would need to be changed to quantify the amount of oil entering the burn and, presumably, its spatial variability.

3. BSEE Study Report:
3.5–To demonstrate the technology proof of concept—Are there any other conclusions that could be drawn that are not adequately addressed in the report? Are there any other issues or concerns with the validity of the methodology or results that were not included in the previous charge questions?
Dr. Oscar Garcia-Pineda From my area of expertise/perspective the report is properly structured, but more details and results are necessary to describe the image processing algorithm in detail. The report needs to include analysis, comparison, and statistics for the many trials to show that the method is valid and can be repeated systematically. The suggestions above would improve the reader's understanding of the experiment setup and addressing these suggestions could add value to work presented here. The report does not describe if the thermal imagery was calibrated with control points. The thermal calibrated imagery should have more value. Reflection from the water can be avoided by changing (increasing) the angle of the cameras. Using radiometric information (temperature instead of only emissivity contrast) can improve the results of the thermal imagery particularly if a higher angle is used to avoid reflections from the specular surface.
Dr. Bill Lehr Doing field work is never simple and the study team is to be commended for their ingenuity in designing and performing this set of experiments. The reviewer hopes that they will accept any critical comments given here in the spirit of constructive recommendations for what was a significant undertaking. Recognizing that spill science is an applied profession, has the case been made that the method proposed will give a significant and consequential improvement over present methods? By consequential, the reviewer means the additional complexity of this approach would be justified by sufficient improvement in response estimates. The report as written does not make a solid case for such consequential improvement at this time unless the concerns discussed above can be resolved.
Mr. Neré Mabile Additional concerns specific to this research include: • Testing/calibrating acoustic thickness measurements through varying emulsion for 0 – 50%. • Testing acoustic thickness measurements with realistic wave action inside a fire boom. • Perform thickness measurements when burning in live conditions while towing boom and currents reflecting varying slick thickness contained in a fire boom. • Integrating technology components in operational conditions with cameras for fire area calculations and thickness measurements.

3. BSEE Study Report:
3.5–To demonstrate the technology proof of concept—Are there any other conclusions that could be drawn that are not adequately addressed in the report? Are there any other issues or concerns with the validity of the methodology or results that were not included in the previous charge questions?
Another big variable for measuring slick thickness is the emulsion factor. I understand that BSEE is already planning for studies with emulsions. The real world offshore conditions will present lots of challenges. Of course, this was a lab study, but if acoustics are to be studied deeper, slick thickness measurements through varying emulsion percent, like 10, 20, 30, 40 and 50 percent would be advisable. And there would be varying emulsion percentages within a contained slick. Acoustical calibration would need to be explored through varying emulsion percent. At around 50% emulsion of "water in oil," in-situ burning ignition is not feasible and has been confirmed in laboratories. Also, during my recent burning operations experience on the DWH oil spill in 2010; the emulsion and weathering conditions prevented crews from accomplishing a sustained ignition on the 5th day after the final day of subsea oil release. From experience, ISB ignition does not occur after four to five days of weathering and emulsification at sea. With a very large burn typical in offshore conditions, other variables would come into play with wind, wind vortexes and the hot air draft principle. A large fire will have varying temperature profiles at different locations in the slick. ISB in the real world will be done a far distance from the source, so weathering and emulsification will occur which will change the slick densities significantly. To qualify the speed of sound, much more work needs to be done with emulsified oil. Except the case of accidental ignition, ISB will not usually be done with fresh oil near the source of a spill. It will typically get approved and employed later in a spill, away from the source where weathering and wave action would create an emulsified slick. Algorithms need to be developed for this scenario along with methods for calibration to a span of percent (%) emulsification up to 50%.
Dr. Tom Weber The report demonstrates what has been previously shown in the literature: sound waves reflect from oil/water and oil/gas interfaces, and if knowledge of the sound speed is in-hand these reflections can be used to determine a layer thickness. The authors demonstrate an ability to make such measurements with a resolution of a mm, or perhaps a few mm. More advanced methods (e.g., broadband pulses) could likely be used to increase this resolution (this technique was employed by Bassett et al., 2015), who used lower-frequencies but broadband pulses). Such methods might be useful for looking at slick and/or emulsion thickness when the oil temperature is constrained (i.e., not during an ISB) to great effect.

5. APPENDIX A: INDIVIDUAL REVIEWER COMMENTS

This appendix provides the individual peer reviewers' comments.

5.1 Dr. Oscar Garcia-Pineda

Quantitative Measurement of *In-Situ* Burn (ISB) Efficiency and Rate	
NAME: Dr. Oscar Garcia-Pineda	**AFFILIATION: Water Mapping, LLC**
DATE: 1/12/2018	
General Impressions:	
The work presented in this report is genuinely creative and innovative. This work is of high importance not only for the understanding of the burning rates during ISB on controlled settings but also because it offers the opportunity to evaluate this method on the cold weather environments as the CRREL lab. The information presented in the report is objective and it shows with clarity the design of the experiment and the methods used for the analysis. I also think the report has some areas of improvement. Minimal misspellings were noticed. I think as a technical report it is complete, however, if possible I would recommend to expand more on areas like: • Repetition and verification of results (e.g., comparing times and rates over same amounts of oil volumes), in case this was done. • Expand on the algorithm for the image processing. • Expand on the image rectification technique. • Include information about calibration of the camera setting, and the thickness measurements with the acoustic system. I agree with the soundness of the conclusions because the results and importance of the test justify the relevance of this effort.	

5.1.1 Quantification of Slick Thickness Charge Questions

Quantitative Measurement of *In-Situ* Burn (ISB) Efficiency and Rate	
NAME: Dr. Oscar Garcia-Pineda	**AFFILIATION: Water Mapping, LLC**
DATE: 1/12/2018	
1. Quantification of Slick Thickness:	
1.1–Are the methods used to measure the oil slick thickness throughout the entire length of the *in-situ* burn tests valid? If yes, explain why these methods are valid. If not, how could the validity of the oil slick thickness measurement methods be improved or more clearly described?	
Maybe the experiment included a calibration test. I did not see much information about this in the report, and this could be an area for expanding on providing more details. I assume that maybe the	

Quantitative Measurement of *In-Situ* Burn (ISB) Efficiency and Rate	
NAME: Dr. Oscar Garcia-Pineda	**AFFILIATION: Water Mapping, LLC**
DATE: 1/12/2018	
1. Quantification of Slick Thickness:	
acoustic system should have been tested under known variable thicknesses to validate that it was calibrated. It is mentioned in the report that a series of burns were made over a scale, it would be nice to see a comparison of results from different tests. One would expect to see the burning times and ratios not identical but well correlated if done under the same circumstances. It's difficult to think of a practical way to improve the experiment per se. Although there are other options to measure oil thicknesses in those ranges (1-12mm), one would have to interrupt the burning to proceed to take measurements. The whole experiment was designed to precisely monitor the sequence and gradient of the burning progression. So, interrupting the burning to measure thickness would be unpractical. Maybe just as a control/monitoring test to validate that the thickness measurements made by the acoustic method are within range. However, this might be out of the scope of the project.	
1.2–Is the method to quantify the speed of sound in oil during *in-situ* burning operations valid? If yes, explain why the method is valid. If not, how could the validity of the speed of sound in oil quantification method be improved or more clearly described?	
As far as I understand, I don't know a better way (practical) to do it.	
1.3–Does the report adequately address the measurement of varying slick thickness throughout the entire slick? If yes, explain why this measurement is adequately addressed. If not, how could these measurements be improved or more clearly described?	
Yes. The distribution of the transducers is graphically explained. If there would be any variances on the slick inside the tank the transducers located in different places would record that variance.	
1.4–Does the report adequately address how the methodology for acoustic slick thickness measurements would be affected by waves and currents in open water conditions? Explain any issues or concerns that might affect the validity of this acoustical methodology in open water conditions.	
The report mentions the possibilities to operate the ROV from a vessel. It mentions that they are testing the acoustic slick thickness measurements within a range of conditions (harbor chop to 23 inches wave height). I think in this regard authors should provide more awareness of the limitations of the acoustic system. In my opinion the ability to operate a system like the ROV shown here would be extremely challenging beyond a strict range of sea state conditions. And it sounds like this is currently under investigation by the authors of this report. However, details about this topic are very limited in the report. The acoustic precision is dependent on the alignment between the transducer and the surface. If turbulence is present, this might compromise the accuracy of the readings since the transducer is no longer perpendicular to the surface where oil is floating. Therefore, the oil layer dynamics will be changing its thickness constantly and maybe would not be captured properly by the sensor.	
1.5–Are the assumptions of the oil thickness algorithm input clearly defined and appropriate (see Sections 2.2.4, 3.1.3, and 3.2.3)? If yes, explain why. If not, explain how those	

Quantitative Measurement of *In-Situ* Burn (ISB) Efficiency and Rate	
NAME: Dr. Oscar Garcia-Pineda	**AFFILIATION: Water Mapping, LLC**
DATE: 1/12/2018	
1. Quantification of Slick Thickness:	
assumptions could be defined more clearly. Provide a rationale for your answer about the appropriateness of the assumptions of the oil thickness algorithm input.	
The description of the oil thickness algorithm is limited. I recommend authors expand on the technical approach and details about the algorithm inputs and handling of the variables.	
1.6–What are the strengths and weaknesses of the slick thickness determination methods? Provide a rationale for each identified strength or weakness.	
I think the most valuable strength is the fact that authors have made it possible at least under the controlled setting shown here. This has the potential to carry out more elaborated testing to understand many other things. Maybe they can create a lab setting to test oil burning rates under different levels of emulsifications, etc. More science can be done by just the fact that a measuring tool has been created. The weakest element on this chain is (as always) the limitations faced for testing on real setting environments. I do aerial mapping of oil spills for living. Observing moving oil is a challenging sport. The success of tactical operations at sea requires the control of many variables that only occur under a limited window of sea state conditions. Operationally speaking, I think the main challenge is the synchronization of the sufficient aerial photography needed (and the proper geo-rectification), but, certainly should be possible. That would need to happen with the proper deployment of the acoustic thickness system that should collect measurements under an array of points under the booming area, also could be possible under specific range of sea state conditions.	

5.1.2 Quantification of Slick Area Charge Questions

Quantitative Measurement of *In-Situ* Burn (ISB) Efficiency and Rate	
NAME: Dr. Oscar Garcia-Pineda	**AFFILIATION: Water Mapping, LLC**
DATE: 1/12/2018	
2. Quantification of Slick Area:	
2.1–Are the methods used to measure the surface area of the burning slick valid? If yes, explain why these methods are valid. If not, how could the validity of the area measurement methods be improved or more clearly described?	
Yes. The experiment is based on the known geometry of the tank, and on a real setting environment, the operators of this system by knowing the length of the booming, they can deduct the area for measurement under ISB.	
2.2–Are the numbers of images, heights, and angles from around the fire adequate for accurate area computations using the photogrammetric methods reported? Explain how the	

Quantitative Measurement of *In-Situ* Burn (ISB) Efficiency and Rate

NAME: Dr. Oscar Garcia-Pineda	AFFILIATION: Water Mapping, LLC

DATE: 1/12/2018

2. Quantification of Slick Area:

approach chosen could affect the validity of the methodology and results.

The report provides a lot of details about the technical setup and connectivity for the cameras. The reader ends up with a general idea of how the rectification is achieved. However, as indicated on previous questions, I think more details about the setting should be included. A sketch describing the range of heights, distances, angles, would be very illustrative.

Is the algorithm capable of handling images collected at different heights and angles? It would be interesting to see if authors achieved similar burning rate results by placing the cameras under different viewing geometry. I can imagine (with my experience as UAS operator) that one can achieve sufficient aerial views of the ISB on a single flight. However, in practice I would struggle to fly my UAS at fixed altitude and a fixed distance from the ISB. Maybe the algorithm can handle views from different angles and distances.

The report states that a number of tests (about 30 burns) were conducted, but the report does not include results on each of those tests. It would improve the understanding of the limitations and merits of the whole approach to see when it does well, when it does not. By having conducted all those tests, authors should provide information about the variables. I don't think is expected that all those burns happened exactly the same; therefore, showing the repeatability of the experiments would be valuable and would reinforce the understanding of the results.

A sketch of the distribution of the cameras (distances, angles, etc.) would help to understand if there was an optimal set of geometric conditions to obtain the best results.

2.3–Does the report adequately address the methods to account for errors from obstructions and limited angles/heights/distances? Explain how the methods used to account for errors could affect the validity or scientific merit of the methodology and results.

The account for errors from obstruction was briefly covered. The report mentions the causes for obstructions and how these challenges can be addressed. However, more details about the account for errors could be included.

The approach used by authors sets a good start, in the future I would recommend to use a moving platform (i.e., a UAS) flying at an equidistance from the center of the burning area (and at different heights). This would provide a 3D (volumetric) perspective and other things can be captured (i.e., density of the smoke plume) that can aid in the calculation of the burning.

2.4–Are the assumptions of the area algorithm input with respect to burning area of the slick clearly defined and appropriate (see Sections 2.1.1, 3.1.1, and 3.2.1)? If yes, explain why. If not, explain how those assumptions could be defined more clearly. Provide a rationale for your answer about the appropriateness of the assumptions of the area algorithm input with respect to burning area of the slick.

Yes. Because the area of the ISB will be known by the length of the booming.

Quantitative Measurement of *In-Situ* Burn (ISB) Efficiency and Rate	
NAME: Dr. Oscar Garcia-Pineda	**AFFILIATION: Water Mapping, LLC**
DATE: 1/12/2018	
2. Quantification of Slick Area:	
A summary of results obtained from different tests would help to validate the algorithm performance. However, the report did not include results from different burns or a comparison of the performance from different times.	
2.5–What are the strengths and weaknesses of the methods for the determination of the area(s) of the burning slick? Provide a rationale for each identified strength or weakness.	
The area of the ISB can be accurately calculated with aerial view and with references from the positions of the vessels. However, the report does not address how the algorithm or the authors plan to address the calculation of the area of a burning slick. There is no mention to the usage of dynamic control points and how they will be incorporated on the mapping (area calculation algorithm). Control points on the open field are a must. If this approach is intended to be taken to the next steps, I would recommend to try much higher altitudes for capturing the tests. Oblique imagery and such low angles (as shown in the report) can cause more specular reflections and distortions that complicate the image processing and would result in inaccurate results. This problem can be solved if higher altitudes for capturing the photography are used. Again, a UAS with thermal and high resolution RGB could help to minimize this problem.	

5.1.3 BSEE Study Report Charge Questions

Quantitative Measurement of *In-Situ* Burn (ISB) Efficiency and Rate	
NAME: Dr. Oscar Garcia-Pineda	**AFFILIATION: Water Mapping, LLC**
DATE: 1/12/2018	
3. BSEE Study Report:	
3.1–To demonstrate the technology proof of concept—Does the report adequately address the methodology to accurately calculate the volume of the entire slick given the differences in thicknesses throughout the entire slick being burned? Explain how this affects the validity or scientific merit of the methodology and results.	
The report lacks on showing results obtained during multiple experiments (repetition). About how this affects the validity, there is a problem if the authors don't show how the performance of the system was measured during repeated trials. If the system works, then authors should be able to demonstrate that the experiment obtained similar results during different tests (or within reasonable variability). They mentioned they performed tests over 30+ times. It would be good to see the variability within those trials. When it works? When it doesn't? What are the main controlled / un-controlled variables, that is not shown and that is a requirement to understand the validation of results.	

Quantitative Measurement of *In-Situ* Burn (ISB) Efficiency and Rate	
NAME: Dr. Oscar Garcia-Pineda	**AFFILIATION: Water Mapping, LLC**
DATE: 1/12/2018	
3. BSEE Study Report:	
3.2–To demonstrate the technology proof of concept—Does the report describe with reasonable accuracy how burn volumes, burn rates, and burn efficiencies are computed? If yes, explain why these computations are described with reasonable accuracy. If not, how could the report describe these computations more clearly or with improved accuracy?	
No, accuracy is not properly shown because there are not results shown for performance from repeated experiments. The report can be improved if analysis of performance over a series of burns is shown. When using the thermal sensors, it is important to always have reference points with known temperatures, that way, when the thermal image is obtained then it can be corrected for any thermal emissivity offsets. There are no thermal control points shown and no calibration description of the thermal camera in the report.	
3.3–To demonstrate the technology proof of concept—Are the limitations and uncertainties clearly identified and adequately characterized for the determination of burn volumes, burn rates, and burn efficiencies? If yes, explain why. If not, how could the limitations and uncertainties for the determination of burn volumes, burn rates, and burn efficiencies be described more clearly or characterized with improved accuracy?	
Uncertainties and limitations are not clearly identified. It is necessary to include the analysis of performance under a number of trials.	
3.4–To demonstrate the technology proof of concept—What are the strengths or weaknesses of the methods used for the computations? Provide a rationale for each identified strength or weakness.	
Computations make sense as presented. This is based on basic arithmetic computations based on the observations of the burn rate, thickness change, etc. The strength of the method is the approach itself. It is a genuine great effort put together by the authors and it represents a strong foundation for further development of science. About the weaknesses of the method, I would recommend to incorporate a more detailed procedure for calibrating sensors, thermal cameras, and more importantly choosing a more strategic set of angles that would improve the accuracy of the computations (avoiding reflections and distortions). Another weakness in the report is that it does not show computations (or results) over several trials.	
3.5–To demonstrate the technology proof of concept—Are there any other conclusions that could be drawn that are not adequately addressed in the report? Are there any other issues or concerns with the validity of the methodology or results that were not included in the	

Quantitative Measurement of *In-Situ* Burn (ISB) Efficiency and Rate	
NAME: Dr. Oscar Garcia-Pineda	**AFFILIATION: Water Mapping, LLC**
DATE: 1/12/2018	
3. BSEE Study Report:	
previous charge questions?	
From my area of expertise/perspective the report is properly structured, but more details and results are necessary to describe the image processing algorithm in detail. The report needs to include analysis, comparison, and statistics for the many trials to show that the method is valid and can be repeated systematically. The suggestions above would improve the reader's understanding of the experiment setup and addressing these suggestions could add value to work presented here. The report does not describe if the thermal imagery was calibrated with control points. The thermal calibrated imagery should have more value. Reflection from the water can be avoided by changing (increasing) the angle of the cameras. Using radiometric information (temperature instead of only emissivity contrast) can improve the results of the thermal imagery particularly if a higher angle is used to avoid reflections from the specular surface.	

5.2 Dr. Bill Lehr

Quantitative Measurement of *In-Situ* Burn (ISB) Efficiency and Rate	
NAME: Dr. William J. Lehr	**AFFILIATION: NOAA**
DATE: 12/18/2017	
General Impressions:	
The project team has conducted a series of interesting experiments that utilize modern technology to improve on a traditional response tool, in-situ burning. The acoustic impedance approach to measure thickness is particularly exciting and should have application well beyond burning. The mapping of surface area by visual and IR cameras is more problematic and it is questionable to the reviewer that it offers sufficient improvement over traditional human eye methods to justify the increased complexity and likelihood of failure if used during the actual burn event. Burn regression rates have been extensively measured and found to be in a relatively narrow band for most oils. Burn times can be measured with a stopwatch. Most burns are over 90% efficient, giving a reliable number at the end of the burn of how much oil was disposed. This number generated by traditional means will be more accurate than other oil mass budget numbers such as volume dispersed or evaporated without going to the increased complexity suggested in this report.	

5.2.1 Quantification of Slick Thickness Charge Questions

Quantitative Measurement of *In-Situ* Burn (ISB) Efficiency and Rate	
NAME: Dr. William J. Lehr	**AFFILIATION: NOAA**
DATE: 12/18/2017	
1. Quantification of Slick Thickness:	
1.1–Are the methods used to measure the oil slick thickness throughout the entire length of the *in-situ* burn tests valid? If yes, explain why these methods are valid. If not, how could the validity of the oil slick thickness measurement methods be improved or more clearly described?	
The research team uses acoustic impedance to measure oil thickness. The technique is unfamiliar to the reviewer but the physics appears to be straightforward. A comparison is made between a sonic pulse signal reflection from the oil-air interface and a weaker reflection from the oil-water interface. The dual transit time through the oil multiplied by the signal velocity in the oil medium gives thickness. Based upon Figure 12, the pulse has a duration ~ 2 microseconds, yielding, from the equation on page 17, a minimum measurable oil thickness by this method of around 1 mm. This should be sufficient for burn measurements since oil thinner than twice this would not sustain a burn. According to the supplemental material, oil temperature varies by several hundred degrees Celsius over the space of a few mm. Since the sound velocity through the oil depends on the spatially varying oil temperature, use of the method would seem to depend on being able to accurately measure this significant temperature change, or at least be able to correctly estimate it for varying oil types and thicknesses. Unfortunately, the latter is the exact unknown property that is to be calculated.	

Quantitative Measurement of *In-Situ* Burn (ISB) Efficiency and Rate

NAME: Dr. William J. Lehr	AFFILIATION: NOAA
DATE: 12/18/2017	

1. Quantification of Slick Thickness:

Figure 13 shows that, once serious burning commences, the resolution of the thickness measurement diminishes, with the transit time measurement spread over about 5 microseconds. Once subsurface water boiling begins, the whole concept of an oil-water layer breaks down but this probably only applies to very shallow water circumstances. Open ocean water should have sufficient convection to provide a necessary heat sink. A separate question arises for oil that becomes, or begins to become, emulsified as the heat from the burn will break the emulsion and create local turbulence. It is the understanding of the reviewer that emulsions were outside the scope-of-work.

A somewhat perplexing graph occurs in the supplemental material where the label is speed of sound versus time but the equation applies to sound speed as a function of temperature (fitted as a cubic). Details on this equation would have been useful.

1.2–Is the method to quantify the speed of sound in oil during *in-situ* burning operations valid? If yes, explain why the method is valid. If not, how could the validity of the speed of sound in oil quantification method be improved or more clearly described?

The reviewer must admit to insufficient expertise to truly assess the method although no obvious scientific irregularities are present. Since the sound velocity through the oil depends on the spatially varying oil temperature, use of the method would seem to depend on being able to measure this significant temperature change, or at least be able to accurately estimate it for varying oil types and thicknesses. Unfortunately, the latter is the exact unknown property that is being sought. According to the supplemental material provided, determination of thermocouple location relative to the top of the slick was done by visual inspection. That hardly seems a valid approach for real burns. The supplemental material says that slick surface in relation to the thermocouples will in the future be determined by a non-linear function of time. The reviewer does not see how this solves the problem. An explanation is needed.

1.3–Does the report adequately address the measurement of varying slick thickness throughout the entire slick? If yes, explain why this measurement is adequately addressed. If not, how could these measurements be improved or more clearly described?

The report on page 53 notes that the project did not attempt to measure spatial variations in the slick, which is unfortunate because one of the most attractive features of this experiment is the capability to measure surface oil thickness at various locations. A practical tool operationally deployed during an actual spill incident could, along with modern remote sensing techniques, finally provide the “holy grail” of spill science, a trustworthy estimate of surface oil volume. Thick oil collected in booms that have an open end to the sea will show some small slope from front to back but the reviewer would be surprised if that small inclination interfered with local thickness measurements by this approach if sufficient acoustic sensors with adequate focus (or a moving sensor with several measurements) were used to calculate the slope. What might be more problematic is spatially varying oil input to an open-ended burn area, causing some cross-sectional thickness differences at the mouth of the opening. During the final burn stages, certain areas will

Quantitative Measurement of *In-Situ* Burn (ISB) Efficiency and Rate	
NAME: Dr. William J. Lehr	**AFFILIATION: NOAA**
DATE: 12/18/2017	
1. Quantification of Slick Thickness:	
stop burning before others but most of the oil will have been consumed by then. The report does not discuss unburned residue and how this could affect thickness and area measurements. It also does not discuss the degree of uncertainty expected from variations in water depth of the ROV, a length scale larger than the oil slick thickness. Presumably the system would automatically correct for this by the timing of the return signal from the oil-water interface but it would be nice to see the details. As a general rule for projects of this nature, one would expect to find extensive tables of measurement results or, at minimum, error bars on the graphs such as Figure 19. Both are lacking in this report.	
1.4–Does the report adequately address how the methodology for acoustic slick thickness measurements would be affected by waves and currents in open water conditions? Explain any issues or concerns that might affect the validity of this acoustical methodology in open water conditions.	
In general the acoustic thickness measurement method seems scientifically sound for non-burning oil under calm surface conditions. Comparison with direct oil mass measurements (Figure 22) supports this conclusion. The research team asserts on page 17 that they compare wave peak measurements when waves are present. Details on how this was achieved are missing from the report. The reviewer wonders if oscillating interfaces of different frequencies will increase spatial return signal scatter. The report on page 53 mentions other studies where slick thickness measurements were successful for wave heights of ~60 cm, greater than the freeboard of many booms used to contain the oil. The reviewer was not tasked to evaluate the report of these other studies but a cursory analysis indicates that the earlier report includes more measurement data results than this report. As a general rule for projects of this nature, one would expect to find extensive tables of measurement results or, at minimum, error bars on the graphs. Both are lacking here. Constant currents should not be a problem for this method since such currents will, by necessity, be less than a knot for the fire booms to contain the oil. Varying currents may be problematic if one wishes to maintain a cohesive slick and not lose control of burning oil. During Deepwater Horizon (DWH), burning oil often escaped from the booms.	
1.5–Are the assumptions of the oil thickness algorithm input clearly defined and appropriate (see Sections 2.2.4, 3.1.3, and 3.2.3)? If yes, explain why. If not, explain how those assumptions could be defined more clearly. Provide a rationale for your answer about the appropriateness of the assumptions of the oil thickness algorithm input.	
The reviewer finds no problems with the algorithm assumptions in the report provided the limitations and expected error ranges are included, something missing from the draft report. All field measurements have limits on their validity and should have known expected accuracy. The	

Quantitative Measurement of *In-Situ* Burn (ISB) Efficiency and Rate	
NAME: Dr. William J. Lehr	**AFFILIATION: NOAA**
DATE: 12/18/2017	

1. Quantification of Slick Thickness:

reviewer searched in vain for serious derivation of the method and its range of application. One obvious question is the degree of horizontal spatial averaging by this method, assuming that the return signal is not giving a specific point reading from the returning sonar. This could be a problem if this method is extended beyond the test case of pure fresh oil to real spills where there may be large variations in degree of weathering for different oil patches that are collected in the same burn operation.

1.6–What are the strengths and weaknesses of the slick thickness determination methods? Provide a rationale for each identified strength or weakness.

It seems likely that the use of acoustic sensors could be included in some AUV or placed on the boom skirt to relay data to the response team prior to the burn. As Figure 13 illustrates, the acoustic method becomes less reliable once significant burning begins. Based on the figure, the reviewer speculates that errors of 50% are possible. Of course, once boil over begins, thickness becomes undefinable.

Neither of these factors need be a drawback to this method in actual burn response. Boil over is a function of the artifice of experiments done in shallow confined pans. In open ocean conditions experiments show that subsurface water circulation prevents a dramatic increase in water temperature (e.g. the NIST mesoscale experiments in 1993). Also, as illustrated with this report (Table 1) and past published reports, there is a relatively constant burn rate for most of the burn with a gentle falloff as the thickness goes from 10 mm to the burn limit of ~2 mm. The reviewer excludes the burning during boil over where the greater exposed surface area temporarily (and artificially) increases the burn rate. Burn rate is usually considered to be relatively independent of oil type. Nevertheless, ASTM F-1788 publishes these minor variations that do depend upon the specific oil. Burn area and duration determines oil volume consumed by fire or transformed into unburned smoke particles (the latter probably about 10% of the oil mass), giving little value to thickness measurements during the actual burn. However, such measurements might be useful, depending upon the particular operation configuration, in providing an estimate of new oil volume captured as a redundant check on volume burned.

One issue not addressed in the report in Section 4 (transitioning towards operational environments) is the matter of hazardous conditions during a large-scale burn. The report mentions that some practice was needed to develop the skill to negotiate the ROV under the burn for the small-scale experiments that were performed. Apparently, some equipment was damaged during the experiments. Large burns are much more dangerous to both personnel and equipment with significantly greater demand on both. Safety especially has to be a major consideration in any new modification to spill cleanup. The report should describe the expected training and precautions to allow this technique to be successfully done with minimum risk to operators and low potential for equipment damage.

5.2.2 Quantification of Slick Area Charge Questions

Quantitative Measurement of *In-Situ* Burn (ISB) Efficiency and Rate	
NAME: Dr. William J. Lehr	**AFFILIATION: NOAA**
DATE: 12/18/2017	
2. Quantification of Slick Area:	
2.1–Are the methods used to measure the surface area of the burning slick valid? If yes, explain why these methods are valid. If not, how could the validity of the area measurement methods be improved or more clearly described?	
The reviewer presumes that one purpose of this project was to do proof of concept to see if this approach could be advanced up the TRL level to full operation. If that is the case, then the burn area measurement methods should be scalable to real field burns. In DWH, that required observers in aircraft. This project used multiple cameras taking simultaneous images. That does not seem practical with aircraft. The study team meets the distortion challenge by using planar homography, a well-established technique to adjust different images to a common reference plane with a common length scale. This technique normally uses reference points to define that common plane. The reference points (or other points at known location from these points) should be observable by all, or most, of the cameras. The report on page 42 claims that two cameras at opposite ends of the burn are sufficient to eliminate false positive readings and smoke obscuration. This seems surprising to the reviewer. Unfortunately, the necessary documentation to check this claim is missing from the report. The reviewer anticipates that surface mapping of the burn area will always present challenges in real burns.	
2.2–Are the numbers of images, heights, and angles from around the fire adequate for accurate area computations using the photogrammetric methods reported? Explain how the approach chosen could affect the validity of the methodology and results.	
It seems that camera number and placement was adequate for the small test burns. The reviewer is curious as to the planned placement of cameras during actual open water burns. Is the concept to put them on support vessels or deploy them on their own floating or airborne platforms? Given the need to maintain a significant safety distance from the burn itself and the impracticality of high mountings of the cameras on their own platforms, it would seem that the view angles could be unfavorable, magnifying the distortion problem. Ideally, the view angle should be less than 30 degrees from the vertical. The project team, in answer to Panel questions, states that their method works for angles as large as 65 degrees. IPIECA recommends a "safe" downwind distance for a thousand square meter in-situ burn as 1 km, a considerable distance from the fire. The report states that distant cameras and lower resolution (150x150 over fire area) provide sufficient accuracy. Unfortunately the calculations used to justify this statement are not included in the report.	
2.3–Does the report adequately address the methods to account for errors from obstructions and limited angles/heights/distances? Explain how the methods used to account for errors could affect the validity or scientific merit of the methodology and results.	

Quantitative Measurement of *In-Situ* Burn (ISB) Efficiency and Rate	
NAME: Dr. William J. Lehr	**AFFILIATION: NOAA**
DATE: 12/18/2017	
2. Quantification of Slick Area:	
For operational burns, obstruction from the booms or other equipment would be relatively small compared to the boomed area. While not a problem for these small-scale burns discussed in the report, NIST reported 10-15% of the mass of the oil converted into smoke particles for large-scale open water burns. At best, the method might be able to estimate the smoke area for a real response burn in open water. As the report notes on page 42, smoke area may be indistinguishable from, or obscuring of, fire area, even in the IR range. The project team suggests that multiple cameras and dynamic phasing of the imagery can overcome the "false positive" burn area by looking at the flame from different angles at different times. The report also states that flame may be separated from smoke by using a different IR frequency band. This may be the case. However, the smoke area can be at different temperatures, encompass the entire smaller burn area and/or change location due to wind fluctuation, making image analysis, and camera placement and timing, problematic. For example, films of the DWH burns show flame appearing well above the water surface and surrounded by smoke.	
2.4–Are the assumptions of the area algorithm input with respect to burning area of the slick clearly defined and appropriate (see Sections 2.1.1, 3.1.1, and 3.2.1)? If yes, explain why. If not, explain how those assumptions could be defined more clearly. Provide a rationale for your answer about the appropriateness of the assumptions of the area algorithm input with respect to burning area of the slick.	
The burn area is observed from multiple cameras, each with a unique view angle, and perhaps in a real incident, elevation. The study team meets the subsequent distortion challenge by using planar homography, a well-established technique to adjust different images to a common reference plane with a common length scale (the water surface and burn area limits). This technique normally uses reference points to define that common plane. The reference points (or other points at known location from these points) should be observable by all, or most, of the cameras. The study should clarify how the method ensures that this is the case when smoke may obscure the images, or alternatively, the number of cameras with clear view that are sufficient for the accuracy of the area measurement by this method if some are obscured. The report hints at two but that seems too few to the reviewer. The report notes on page 40 that the results of 30 burns can be used to empirically determine error and verify the limits of forming an accurate homography but does not provide those results so it is difficult to know if the errors are within an acceptable range. In answer to Panel questions, the project team noted that only single RGB pixel results were used define flame on the water surface. The algorithm in their reply seems woefully inadequate to the reviewer. At minimum, adjustments need to be made to define flame only on the water-oil surface plane as opposed to flame in planes above the water surface. Rules should be based at least on differences with surrounding pixels, not the absolute readings of any individual pixel. Better IR will probably be required. In the reviewer's judgment, this is one of the most important gaps in the report if the plan is to move up the TRL ladder.	
2.5–What are the strengths and weaknesses of the methods for the determination of the area(s) of the burning slick? Provide a rationale for each identified strength or weakness.	

Quantitative Measurement of *In-Situ* Burn (ISB) Efficiency and Rate	
NAME: Dr. William J. Lehr	**AFFILIATION: NOAA**
DATE: 12/18/2017	
2. Quantification of Slick Area:	
The most significant challenge that burn area measurement by visual and IR recording would face in an operational application would be obscuring of the burn area by produced smoke. While not a problem for the small-scale burns discussed in the report, NIST reported 10-15% of the mass of the oil converted into smoke particles for large-scale open water burns. At best, the proposed method might be able to estimate the smoke area for a real response burn in open water. As the report notes on page 42, smoke area may be indistinguishable from, or obscuring of, fire area, even in the IR range. The project team suggests that multiple cameras and dynamic phasing of the imagery can overcome the "false positive" burn area by looking at the flame from different angles at different times. The report also states that flame may be separated from smoke by using a different IR frequency band. This may be the case. However, the smoke area can be at different temperatures, encompass the entire smaller burn area and/or change location due to wind fluctuation, making image analysis, and camera placement and timing, problematic. For example, films of the DWH burns show flame appearing well above the water surface and surrounded by smoke. This may be much less of a problem from smoke from small contained burns such as the CRREL ice burns but then burn area is more constrained to begin with. Multiple cameras seem useful in cases where the flame can be clearly distinguished from the smoke for at least one view, allowing correction for such artifacts as flame reflection from the water surface.	

5.2.3 BSEE Study Report Charge Questions

Quantitative Measurement of *In-Situ* Burn (ISB) Efficiency and Rate	
NAME: Dr. William J. Lehr	**AFFILIATION: NOAA**
DATE: 12/18/2017	
3. BSEE Study Report:	
3.1–To demonstrate the technology proof of concept—Does the report adequately address the methodology to accurately calculate the volume of the entire slick given the differences in thicknesses throughout the entire slick being burned? Explain how this affects the validity or scientific merit of the methodology and results.	
The reviewer was uncertain when more than one transducer was used in any of the experiments. Presumably, more than one unit that are each spatially separated, or a moving unit that transits the burn area would provide spatially varying thickness measurements, given that the acoustic signal in each case was sufficiently focused. As noted on page 52, the project did not attempt to measure spatial variations of thickness so it is not possible to address methodology for spatial thickness variation from the report.	
3.2–To demonstrate the technology proof of concept—Does the report describe with reasonable accuracy how burn volumes, burn rates, and burn efficiencies are computed? If	

Quantitative Measurement of *In-Situ* Burn (ISB) Efficiency and Rate	
NAME: Dr. William J. Lehr	**AFFILIATION: NOAA**
DATE: 12/18/2017	

3. BSEE Study Report:

yes, explain why these computations are described with reasonable accuracy. If not, how could the report describe these computations more clearly or with improved accuracy?

The calculations of burn volumes, rates, and efficiencies are simple and straightforward. Unfortunately, it is not possible from the report to truly assess the necessary accuracy of these numbers since no measurements come with error bars. The report would be more clear if it were to include information on the actual values used, and expected uncertainties in these parameters in their calculations. For example, the material discussed on pages 26-28 is confusing to the reviewer. The report shows some differences between burn rate as measured by mass (volume) loss and burn rate as calculated by thickness change. Is the difference simply due to water loss in the mass (volume) calculation? The bottom of Figure 25 indicates that the burn rate decreased significantly for thickness from 6 to 10 mm. This strange result contradicts the Buist et. al. study in Table 1 above the graph. One would expect that increased oil thickness would act as insulation, reducing heat loss to the water and producing higher burn rate. The reviewer assumes that the anomalous results in the graph are due to lack of steady burning early on, when the oil thickness was high, combined later on with the beginning of boil over. If so, the report should say this.

[editorial note –Table 2, Volume is not measured in cm2]

3.3–To demonstrate the technology proof of concept—Are the limitations and uncertainties clearly identified and adequately characterized for the determination of burn volumes, burn rates, and burn efficiencies? If yes, explain why. If not, how could the limitations and uncertainties for the determination of burn volumes, burn rates, and burn efficiencies be described more clearly or characterized with improved accuracy?

The short answer to this question is no. There are, for example, no error bars on any of the graphs. The report claims that there were 30 burn experiments that can be used to empirically determine error but the data and calculations are not included. For example, burn rate calculation accuracy versus peak wave height would be a useful chart, as would a graph of area estimate uncertainty as a function of average view angle. This lack of data result reports seems to be an obvious oversight for what would otherwise be considered a good research exercise.

3.4–To demonstrate the technology proof of concept—What are the strengths or weaknesses of the methods used for the computations? Provide a rationale for each identified strength or weakness.

The strength in the calculations used in the report is that they are simple and easily understood. This is important when explaining results during a spill emergency to non-technical decision makers. While the report establishes proof of concept for measuring thickness during the burn, it does not give a rationale for substituting well-documented burn rates for something calculated on the fly during an emergency operation. Moreover, some of the more complex calculations such as signal to noise ratio from the acoustic measurements and view correction uncertainty using planar homography are not included so it is difficult to evaluate method accuracy. If the intent is to advance this technology to final deployment, better algorithms to define burn area boundary edge

Quantitative Measurement of *In-Situ* Burn (ISB) Efficiency and Rate	
NAME: Dr. William J. Lehr	**AFFILIATION: NOAA**
DATE: 12/18/2017	
3. BSEE Study Report:	
need to be developed. The reviewer disagrees with the report conclusion that the work advanced the technology to TRL 5.	
3.5–To demonstrate the technology proof of concept—Are there any other conclusions that could be drawn that are not adequately addressed in the report? Are there any other issues or concerns with the validity of the methodology or results that were not included in the previous charge questions?	
Doing field work is never simple and the study team is to be commended for their ingenuity in designing and performing this set of experiments. The reviewer hopes that they will accept any critical comments given here in the spirit of constructive recommendations for what was a significant undertaking. Recognizing that spill science is an applied profession, has the case been made that the method proposed will give a significant and consequential improvement over present methods? By consequential, the reviewer means the additional complexity of this approach would be justified by sufficient improvement in response estimates. The report as written does not make a solid case for such consequential improvement at this time unless the concerns discussed above can be resolved.	

5.3 Mr. Neré Mabile

Quantitative Measurement of *In-Situ* Burn (ISB) Efficiency and Rate	
NAME: Mr. Neré Mabile	**AFFILIATION: Mabile Resources, Inc.**
DATE: 12/29/2017	
General Impressions:	

First, it is truly exciting to know that research is moving forward in the area of automated burn rate and efficiency data gathering to in-turn, calculate a more accurate burn volume of oil removed. I am looking forward to transitioning from lab to the offshore “real world” with several challenges ahead.

Information Presented

My overall impression is that some good laboratory work has been done in testing and validating automated fire area estimations. I encourage more work in this direction. I did not agree with the claimed TRLs reported by the researchers in this report.

The lab work involving acoustical measurement for slick thickness was interesting, but not practical. In my opinion, applying real-time slick thickness measurement during offshore ISB is not practical and really not necessary. Acoustics measurement was tested with fresh oil only and ISB will involve emulsions most of the time. The burn rate study was a re-examination of the slick thickness while burning in pool fires, which was done many times before. Transition to “real world” would include studies on acoustically measuring oil emulsion thicknesses.

The dynamic, real-time volume calculations with burning different crude oils and studying slick thickness have been done before through NIST (Building and Fire Research Lab) and other commercial labs. There is even data from Russian field studies as far back as the 1950s. In my opinion, we know enough about burn rates (or the oil removal rates) with different crudes and emulsified crudes at varying thicknesses. Of course, the acoustic measuring device had to be proven. Although it is nice to have a re-confirmation on burn rates with different measuring devices while studying small pool fires. The burn rates reported correlates well with many other studies. The big challenge will be to measure instantaneous burn rates with a realistic offshore burn, much larger in size, with wave action, and varying oil/emulsion thicknesses contained within a towed boom system. Although, the report did mention the lack of wave action and current affects study.

From an operations perspective, I would encourage research more focused on figuring out a “practical” way to get a reliable average value of the emulsified and varying slick thicknesses within a burning slick towed by a fire boom system. And then, designing a practical fire area monitoring/measuring method for deploying in an offshore environment and typical conditions.

My general impression is that technology deployment feasibility studies should be done for real world application in order to steer research direction towards the highest potential for success.

From an operations perspective, the largest margin of error is the fire area estimation, because of

Quantitative Measurement of *In-Situ* Burn (ISB) Efficiency and Rate	
NAME: Mr. Neré Mabile	**AFFILIATION: Mabile Resources, Inc.**
DATE: 12/29/2017	
General Impressions:	
the challenge in maintaining a good quality sustained surveillance. I hope to see more work focused with the application of photogrammetry and developing some reality solutions to determine how to successfully implement automated fire area monitoring from feasible platforms. For Burn Volume Estimation, the margin of error with burn rate and slick thickness assumptions are very small compared to estimating fire area on a constant, accurate and consistent basis. Clarity and Accuracy Based on the comments above, the TRLs (Technology Readiness Levels) were not appropriately referenced in the research report. I would say that a "Partial Simulation" was done. The last paragraph in the report on page 7, states "Specifically, at the start of this project the ability to directly measure the volume of burning did not exist." This is inaccurate. As mentioned before, studies with NIST and other commercial labs accomplished this before. Also it is unclear on the accuracy of the sound travel calibration through oil. The research report did not adequately explain how calibration was handled through different heat ranges with depth near the surface of the oil slick? Calibration accuracy? In this report, there was an absence of measuring equipment accuracy or margin of error notation. Soundness of Conclusions The report concludes that this work created the capability to measure the instantaneous burn rate and efficiency during ISB. In the lab yes, but there are big steps to implement in reality. The conclusion should reflect the capability is in a lab environment with no waves, no emulsion with the total flexibility of placing cameras in ideal positions.	

5.3.1 Quantification of Slick Thickness Charge Questions

Quantitative Measurement of *In-Situ* Burn (ISB) Efficiency and Rate	
NAME: Mr. Neré Mabile	**AFFILIATION: Mabile Resources, Inc.**
DATE: 12/29/2017	
1. Quantification of Slick Thickness:	
1.1–Are the methods used to measure the oil slick thickness throughout the entire length of the *in-situ* burn tests valid? If yes, explain why these methods are valid. If not, how could the validity of the oil slick thickness measurement methods be improved or more clearly	

Quantitative Measurement of *In-Situ* Burn (ISB) Efficiency and Rate

NAME: Mr. Neré Mabile	**AFFILIATION: Mabile Resources, Inc.**
DATE: 12/29/2017	

1. Quantification of Slick Thickness:

described?

The methods described, I think are valid. In section 2.2.4, the data reflects the burn stopping when the measured slick thickness reached 2mm. This correlates very well with many laboratory test done in the past. At 2mm, the water acts as a heat sink and starves the fire of the required heat to vaporize crude oil at the surface of the slick. This has been the established thickness threshold where the oil insulative qualities are not enough to vaporize the oil to sustain combustion.

1.2–Is the method to quantify the speed of sound in oil during *in-situ* burning operations valid? If yes, explain why the method is valid. If not, how could the validity of the speed of sound in oil quantification method be improved or more clearly described?

I'm not sure that the calibration is accurate and do not understand how calibration can be accomplished accurately when there is a variable heat range throughout the slick thickness under the burn or fire. The accuracy of measurement instruments used in quantifying the speed of sound was not portrayed.

1.3–Does the report adequately address the measurement of varying slick thickness throughout the entire slick? If yes, explain why this measurement is adequately addressed. If not, how could these measurements be improved or more clearly described?

For this laboratory test, I think yes. But to improve these measurements, thicker slicks need to be studied and measured. This is relating to transition to offshore, actual conditions. A fire boom will create slicks up to 16" to 18" in depth right near the apex of the "U" shaped boom. Pulling fire boom at ½ to ¾ knot, will build up oil to a depth reaching the bottom of the boom skirt. The slick will vary in depth with a slight thickening at the leading edge of the boom with increasing thickness towards the apex. This dynamic slick thickness variation inside of a fire boom will depend on the type of oil, viscosity, gravity, speed of tow, fluid dynamics, drag coefficients, etc.

Page 23 of the report mentions and recognizes the fact that slick thickness for larger burns will vary in thickness.

1.4–Does the report adequately address how the methodology for acoustic slick thickness measurements would be affected by waves and currents in open water conditions? Explain any issues or concerns that might affect the validity of this acoustical methodology in open water conditions.

No, the report does not address this as mentioned within the text on page 53 at end of Section 4.2. Concerns that might affect the validity in open water, as mentioned before, would be the presence of emulsions (created by waves) affecting density and affecting calibration and measurement. The emulsification factor would also vary throughout the slick.

Also, from prior testing of small waves (5 and 10cm) in 1980 noted by Tam and Purves; the presence of waves reduced the burning rates by increasing the heat transfer to the underlying water. Buist and McAllister (1981) reported reduced burn times at constant tow speeds with increasing regular wave heights, but no decrease in visible combustion intensity. The latter test

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NAME: Mr. Neré Mabile	**AFFILIATION: Mabile Resources, Inc.**
DATE: 12/29/2017	
1. Quantification of Slick Thickness:	
was done at the Ohmsett test facility. Buist and McAllister (1981) also noted that the effects of currents on ISB burning rates are negligible. Ref: Tam, W.K. and W. F. Purves. 1980. Experimental evaluation of oil spill combustion promoters. Proceedings of the Oceans '80 International Forum on Ocean Engineering in the 80s. IEEE, Piscataway, NJ. pp. 415-422. Ref: Buist, I.A. and I.R. McAllister. 1981. Dome Petroleum's fireproof boom --- development and testing to date. Proceedings of the Fourth Arctic and Marine Oil Spill Program Technical Seminar, June 16-18, Edmonton, Alberta. Environment Canada, Ottawa, Ontario. pp. 479-497.	
1.5–Are the assumptions of the oil thickness algorithm input clearly defined and appropriate (see Sections 2.2.4, 3.1.3, and 3.2.3)? If yes, explain why. If not, explain how those assumptions could be defined more clearly. Provide a rationale for your answer about the appropriateness of the assumptions of the oil thickness algorithm input.	
This is not my area of expertise.	
1.6–What are the strengths and weaknesses of the slick thickness determination methods? Provide a rationale for each identified strength or weakness.	
The weakness are: 1. The thickness is measured only at the point in the slick of each of the transducer probes and does not represent the entire profile of the slick. 2. The calibration of sound transducers is difficult with varying temperatures within the slick during ISB. 3. Emulsification variability will be a real challenge for sound calibration, which was not included in this research. 4. From an operational perspective it is not easily envisioned how transducer probes could be deployed to provide useful information during an offshore ISB. I envision a netting structure suspended below a fire boom with fixed transducers. Floating debris would be a problem. ROV deployment would be very expensive and not practical to cover several burns at the same time.	

5.3.2 Quantification of Slick Area Charge Questions

Quantitative Measurement of *In-Situ* Burn (ISB) Efficiency and Rate	
NAME: Mr. Neré Mabile	**AFFILIATION: Mabile Resources, Inc.**
DATE: 12/29/2017	
2. Quantification of Slick Area:	
2.1–Are the methods used to measure the surface area of the burning slick valid? If yes, explain why these methods are valid. If not, how could the validity of the area measurement	

Quantitative Measurement of *In-Situ* Burn (ISB) Efficiency and Rate

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2. Quantification of Slick Area:

methods be improved or more clearly described?

Yes, it appears that the methods presented are valid and part of existing technology frequently used for other applications.

An improvement would be to also test in darkness application. Offshore burning could extend into the night and this was the case a few times during the DWH response.

The challenge to real world transition will be to design procedure/methodology to maintain constant and sustained fire area monitoring (in daylight and darkness) to capture an accurate burn volume. The fire area is the most important and most significant value to the volume equation that is usually hard to acquire. Burn rate can be estimated, burn duration is easy to obtain and record, but fire area accuracy is most challenging.

2.2–Are the numbers of images, heights, and angles from around the fire adequate for accurate area computations using the photogrammetric methods reported? Explain how the approach chosen could affect the validity of the methodology and results.

Not my expertise, but I think the characteristics of the data gathering are adequate.

The approach heights and angles might be different if dealing with very large fires where there is oxygen starvation in the center creating low burn efficiency, resulting in very dark black smoke. With high winds, the smoke plume could lay down and cause potential obstructions.

2.3–Does the report adequately address the methods to account for errors from obstructions and limited angles/heights/distances? Explain how the methods used to account for errors could affect the validity or scientific merit of the methodology and results.

This is not my area of expertise, but the methodology seems to account for errors of obstruction.

One point, if conducting an ISB with high winds, the smoke plume lays down a lot and black and gray smoke might affect the validity and might account for error.

I can’t help but think about transition to “real world” where burns can last 12 hours or more. This technology is not new, but applying this constant fire area monitoring to large offshore burns 200 or 300 feet in diameter would be new.

2.4–Are the assumptions of the area algorithm input with respect to burning area of the slick clearly defined and appropriate (see Sections 2.1.1, 3.1.1, and 3.2.1)? If yes, explain why. If not, explain how those assumptions could be defined more clearly. Provide a rationale for your answer about the appropriateness of the assumptions of the area algorithm input with respect to burning area of the slick.

Not my area of expertise.

But, it is noticeable that the fire area demonstration photos on page 15 of the report seem to show

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2. Quantification of Slick Area:	
some normalizing of areas where the odd shapes of fire occur. The margin of error or accuracy is not clearly defined. What pixel resolution is used and how much estimation or "rounding off" is being done with these odd fire shapes? Large burns will have many of these odd shapes and edges throughout the burn.	
2.5–What are the strengths and weaknesses of the methods for the determination of the area(s) of the burning slick? Provide a rationale for each identified strength or weakness.	
The strengths are: using automated equipment to "tirelessly" and more accurately perform the fire area estimation. The weaknesses include unclear definition of the margin of error or accuracy. The "rounding" of areas were done, but not clearly defined how.	

5.3.3 BSEE Study Report Charge Questions

Quantitative Measurement of *In-Situ* Burn (ISB) Efficiency and Rate	
NAME: Mr. Neré Mabile	**AFFILIATION: Mabile Resources, Inc.**
DATE: 12/29/2017	
3. BSEE Study Report:	
3.1–To demonstrate the technology proof of concept—Does the report adequately address the methodology to accurately calculate the volume of the entire slick given the differences in thicknesses throughout the entire slick being burned? Explain how this affects the validity or scientific merit of the methodology and results.	
No, it really does not. In Table 2 in the report section 2.3, The volume is reported in units of area in square centimeters. The volume calculation should have been the root of this report and explained more thoroughly.	
3.2–To demonstrate the technology proof of concept—Does the report describe with reasonable accuracy how burn volumes, burn rates, and burn efficiencies are computed? If yes, explain why these computations are described with reasonable accuracy. If not, how could the report describe these computations more clearly or with improved accuracy?	
The report could describe the computation results better….. If the graph in Figure 23, Section 2.3; would depict the Y-axis "label" and "units."	
3.3–To demonstrate the technology proof of concept—Are the limitations and uncertainties clearly identified and adequately characterized for the determination of burn volumes, burn rates, and burn efficiencies? If yes, explain why. If not, how could the limitations and uncertainties for the determination of burn volumes, burn rates, and burn efficiencies be described more clearly or characterized with improved accuracy?	

Quantitative Measurement of *In-Situ* Burn (ISB) Efficiency and Rate

NAME: Mr. Neré Mabile	**AFFILIATION: Mabile Resources, Inc.**

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3. BSEE Study Report:

Burn rates and efficiencies were characterized adequately and the results correlated well with many previous studies done in previous laboratories. Burn volume was not clearly or adequately characterized.

3.4–To demonstrate the technology proof of concept—What are the strengths or weaknesses of the methods used for the computations? Provide a rationale for each identified strength or weakness.

Volume computations were not clearly defined. Wrong units were logged in Table 2 of the report section 2.3. The accuracy of fire area calculation was not clearly defined as far as the area normalizing.

3.5–To demonstrate the technology proof of concept—Are there any other conclusions that could be drawn that are not adequately addressed in the report? Are there any other issues or concerns with the validity of the methodology or results that were not included in the previous charge questions?

Additional concerns specific to this research include:

- Testing/calibrating acoustic thickness measurements through varying emulsion for 0 – 50%.
- Testing acoustic thickness measurements with realistic wave action inside a fire boom.
- Perform thickness measurements when burning in live conditions while towing boom and currents reflecting varying slick thickness contained in a fire boom.
- Integrating technology components in operational conditions with cameras for fire area calculations and thickness measurements.

Another big variable for measuring slick thickness is the emulsion factor. I understand that BSEE is already planning for studies with emulsions.

The real world offshore conditions will present lots of challenges. Of course, this was a lab study, but if acoustics are to be studied deeper, slick thickness measurements through varying emulsion percent, like 10, 20, 30, 40 and 50 percent would be advisable. And there would be varying emulsion percentages within a contained slick. Acoustical calibration would need to be explored through varying emulsion percent. At around 50% emulsion of “water in oil,” in-situ burning ignition is not feasible and has been confirmed in laboratories. Also, during my recent burning operations experience on the DWH oil spill in 2010; the emulsion and weathering conditions prevented crews from accomplishing a sustained ignition on the 5th day after the final day of subsea oil release. From experience, ISB ignition does not occur after four to five days of weathering and emulsification at sea.

With a very large burn typical in offshore conditions, other variables would come into play with wind, wind vortexes and the hot air draft principle. A large fire will have varying temperature profiles at different locations in the slick. ISB in the real world will be done a far distance from the

Quantitative Measurement of *In-Situ* Burn (ISB) Efficiency and Rate	
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3. BSEE Study Report:	

source, so weathering and emulsification will occur which will change the slick densities significantly. To qualify the speed of sound, much more work needs to be done with emulsified oil.

Except the case of accidental ignition, ISB will not usually be done with fresh oil near the source of a spill. It will typically get approved and employed later in a spill, away from the source where weathering and wave action would create an emulsified slick. Algorithms need to be developed for this scenario along with methods for calibration to a span of percent (%) emulsification up to 50%.

5.4 Dr. Tom Weber

Quantitative Measurement of *In-Situ* Burn (ISB) Efficiency and Rate	
NAME: Dr. Thomas Weber	**AFFILIATION: University of New Hampshire**
DATE: 12/29/2017	
General Impressions:	

The idea behind this work is that it is of critical importance to measure the amount of oil removed by in-situ burning (ISB), as well as to measure the efficiency of ISB (i.e., how much was burned compared to how much was left). ISBs can be dynamic, where oil booms are towed to capture additional oil after ignition, and so knowledge of a burn rate is an important aspect of quantifying the amount of oil removed. As described during the panel review for this work, ISB assessment methods used during the Deepwater Horizon oil spill involved estimating the area of the ignited portion of the ISB, multiplying this by a priori estimates of burn rate, and integrating over time to get a total number of barrels removed. Area estimates were conducted from visual inspection of the fire during overflights with a fixed-wing aircraft, using the boom as a size reference. Burn rates were taken from previous laboratory measurements (rates have been established for different burn types).

The present work seeks to improve on current methods for assessing ISB by measuring and monitoring the ignited slick area using IR and/or visible camera, and ignited slick thickness using upward-looking acoustic echo sounders.

The report is well-organized into sections that focus on the two basic measurement techniques, one for area and one for thickness, and on assessing these techniques in different scenarios (e.g., in the ice). However, the description of the work conducted often lacks the detail required for a full technical review. There are some statements which are not self-evident and lack the literature references to support them. Several figures require color-scales or contours (or both) in order to more easily interpret them. Some of these issues are described within this review.

The methodology for assessing thickness appears to be flawed. One of these flaws is based on the premise that a measurement of thickness – or change in thickness over time - can be used to establish a burn rate. Such a burn rate could be established for a static environment, such as those tested in the reported laboratory work, but the description of ISB presented during the panel review was of a dynamic burn, where vessels towed the boom system (after ignition) to capture new oil to keep the burn going. This means that establishing a rate requires knowledge of how much is leaving the boomed slick (via burning, ignoring oil that slips under the booms as appears to sometimes happen) and how much oil is entering the boomed slick during towing. The present work only reports on thickness in the boom, and is this insufficient for determining a burn rate for the types of ISBs employed during the Deepwater Horizon response. This issue was not addressed in the report.

A second technical flaw was also unaddressed in the report. The measurement of thickness is inferred from a time-of-flight measurement of an acoustic pulse. Converting time to thickness requires knowledge of the temperature profile in the burning slick, noting that the speed of sound in oil changes by a few m/s per degree Celsius change in temperature and that the temperature

Quantitative Measurement of *In-Situ* Burn (ISB) Efficiency and Rate	
NAME: Dr. Thomas Weber	**AFFILIATION: University of New Hampshire**
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change from the ignited portion of the slick to the ocean water is several 100's of degrees Celsius. Assuming that these temperature profiles are not constant throughout the burn (and they did not appear constant during the laboratory measurements), converting the acoustic time-of-flight measurements would require measurements of the temperature profile of the slick. Such a measurement of this profile includes knowledge of the location of both the top and bottom of the slick, and such knowledge would then obviate the need for the acoustic measurement in the first place. There are additional concerns about converting measurements of temperature to the speed of sound in an oil which has undergone some unknown amount of weathering and/or emulsification. Measuring the area of an ignited portion of an ISB via camera seems much more feasible, particularly given that this is essentially what is done now. Replacing the subjectivity of human interpretation of area with an automated method seems a worthwhile endeavor.	

5.4.1 Quantification of Slick Thickness Charge Questions

Quantitative Measurement of *In-Situ* Burn (ISB) Efficiency and Rate	
NAME: Dr. Thomas Weber	**AFFILIATION: University of New Hampshire**
DATE: 12/29/2017	
1. Quantification of Slick Thickness:	
1.1–Are the methods used to measure the oil slick thickness throughout the entire length of the *in-situ* burn tests valid? If yes, explain why these methods are valid. If not, how could the validity of the oil slick thickness measurement methods be improved or more clearly described?	
The thickness measurement requires the measurement of echoes from both the oil and air/water (or flame/water) interfaces and an estimate of the harmonic mean sound speed in the oil. The general "echo sounding" principle behind this approach is valid, and the report shows clear evidence of resolvable echoes from both interfaces. This in and of itself is not surprising, and similar work has been conducted in "static" environments where the oil is not ignited (see, for example, Bassett et al., JASA 137(1), EL32-EL38, 2015, who were measuring 40 mm thick layers of oil using broadband echo sounders operating between 200-300 kHz). The ignition of the oil in the present work raises some additional challenges, however, and it is not clear how these challenges will be overcome. The largest challenge with this method is related to converting travel time to distance, which requires knowledge of the sound speed profile through the oil layer. The sound speed in oil is a strong function of temperature, as shown in this report, varying by several hundreds of m/s over the temperature ranges relevant for burning oil (ocean temperatures to several hundred degC).	

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NAME: Dr. Thomas Weber	AFFILIATION: University of New Hampshire
DATE: 12/29/2017	

1. Quantification of Slick Thickness:

Temperature profiles in the report show strong gradients – of the order of 100 degC per mm – with variations throughout the burning process. The acoustic travel time measurements would require knowledge of the harmonic mean sound speed through the oil in order to estimate the layer thickness. But knowledge of the harmonic mean sound speed requires a temperature profile, which in turn requires temperature sensors to be placed in the slick. Further, these temperature sensors have to be vertically referenced to the slick. The location of the top of the slick must be known, which seems challenging given the results provided in the report which do not show an easy path to discriminating between the upper portion of the ignited slick and the flame above it. Information provided with the report suggests that the laboratory method relied on a visual estimate for which temperature sensors were submerged, including a straight-line fit for the height of the slick as it burned off. Note that the acoustic measurements do not match a straight line fit, and so the temperature profiles used for this work represent only a crude estimate. The requirement for an accurate temperature profile takes away from the ease with which the acoustic measurement can be made, even in a laboratory setting.

Remaining on the topic of converting travel time to distance, there is an important link between draft-report-Figure 13 (acoustic result) and draft-report-Figure 14 (temperature), although it is not clear whether these data are from the same experiment. According to Figure 5, the acoustic sensor and the thermocouples are fixed with respect to one another, and the 16 thermocouples are at fixed altitudes (not depths, as is described in the manuscript). Assuming that the highest thermocouple was at the top of the slick prior to the burn, as described in Figure 14, much of the temperature measurements are taken above the surface of the burning slick, presumably in the flame. That is, by approximately 200 seconds in Figure 14, about 7 mm of oil should have been burned according to Figure 19 and Figure 21. This suggests that the interpretation of Figure 15 is incorrect: these temperatures are partially from the air/flame (the top 4 mm of Figure 15-left, and four times greater than 175 seconds of Figure 15-right) and not all in the slick.

1.2–Is the method to quantify the speed of sound in oil during *in-situ* burning operations valid? If yes, explain why the method is valid. If not, how could the validity of the speed of sound in oil quantification method be improved or more clearly described?

The method for quantifying the speed of sound in oil – making measurements of travel time over a fixed distance as a function of temperature – is adequate for use in the laboratory experiments described in this report. The only limitation is the range of temperatures over which the sound speed has been measured, which do not extend to the high temperatures observed during the laboratory experiments. A polynomial fit was employed to extrapolate the speed of sound to higher temperatures, but the uncertainty of this fit was not established and presumably some unknown bias is retained in the final measurements of thickness.

I would further note that the report authors require a reference for their statement that "the speed of sound in a fluid is directly related to the viscosity" made in the draft report. Sound speed is typically considered to be related to the bulk modulus and the density of the fluid, and independent

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DATE: 12/29/2017	
1. Quantification of Slick Thickness:	
of the viscosity.	
1.3–Does the report adequately address the measurement of varying slick thickness throughout the entire slick? If yes, explain why this measurement is adequately addressed. If not, how could these measurements be improved or more clearly described?	
The report describes the use of up to eight acoustic transducers in the laboratory tests (Figure 5). The results of the measurements from these multiple transducers are not included in the report – only measurements from one transducer per burn are described. The one exception to this is the in-ice burns, where measurements from a single frame-mounted and a single ROV-mounted transducer are described, but with no “attempt to measure the spatial variations of the slick thickness” according to the draft report. So no, the report does not address the measurement of varying slick thickness throughout the entire slick. Given the constrained laboratory setting of the experiments, it is not clear that the slick thickness should even vary during the burns. It would still be valuable, however, to explore the variations in the thickness measurements between the different sensors, with some attempt to partition the inevitable differences between actual changes in thickness and measurement uncertainty/bias.	
1.4–Does the report adequately address how the methodology for acoustic slick thickness measurements would be affected by waves and currents in open water conditions? Explain any issues or concerns that might affect the validity of this acoustical methodology in open water conditions.	
This is not addressed in the report. Waves and currents could potentially create emulsions of oil and water, or gas bubbles, which could lead to increased volume reverberation below the slick and confound the detection of the interfaces. The methodology for detecting the interfaces relies on identifying the same cycle of the reflected waves for different interfaces, and volume reverberation could make this unreliable. Other approaches that rely on match filtering and/or the signal amplitude envelope may be more robust. Waves and currents could also hinder the safe-operation of placing an ROV underneath the surface of burning oil.	
1.5–Are the assumptions of the oil thickness algorithm input clearly defined and appropriate (see Sections 2.2.4, 3.1.3, and 3.2.3)? If yes, explain why. If not, explain how those assumptions could be defined more clearly. Provide a rationale for your answer about the appropriateness of the assumptions of the oil thickness algorithm input.	
The measurement algorithm itself is rather simple – the thickness is defined to be the time difference of arrival for the two interface returns, multiplied by the sound speed and divided by 2. It does not appear that there is an invalid assumption in the formulation that would cause a problem for this method, but rather that some of these parameters (sound speed) are difficult to	

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1. Quantification of Slick Thickness:	
know, as described above. There are some gaps in the description for the draft report that make assessing assumptions difficult. In section 2, for example, there is no mention of how the temperature was used to convert to sound speed. Was a harmonic mean used? Given that the thermocouples were fixed in place, how was the top of the slick determined for the temperature measurements (which were in turn required to calculate sound speed)?	
1.6–What are the strengths and weaknesses of the slick thickness determination methods? Provide a rationale for each identified strength or weakness.	
The strength of the method is the simplicity with which measurements of the travel time for echoes can be made. This methodology has been proven in a variety of settings, including for layers of oil, as has been reported in the literature. The main weakness of the method is the requirement to measure in-situ temperature over very fine scales, vertically referenced to the slick, so as to convert the measurements of travel time to distance. Knowledge of the location of the top of the slick, which is required to generate a temperature profile, seems particularly difficult. Given the straight-line-fit approach to the upper interface of the slick reported by the report authors in response to follow-up questions on the draft-report, the issue of determining valid temperature profiles for the laboratory experiments remains unaddressed. A second weakness is the requirement for knowledge of the temperature-dependent sound speed of oils, which could only be measured over a finite range of temperatures, and must be made for each type of oil (or oil/water emulsion) used.	

5.4.2 Quantification of Slick Area Charge Questions

Quantitative Measurement of *In-Situ* Burn (ISB) Efficiency and Rate	
NAME: Dr. Thomas Weber	**AFFILIATION: University of New Hampshire**
DATE: 12/29/2017	
2. Quantification of Slick Area:	
2.1–Are the methods used to measure the surface area of the burning slick valid? If yes, explain why these methods are valid. If not, how could the validity of the area measurement methods be improved or more clearly described?	
The report describes the use of cameras from multiple angles to measure the surface area of the burning slick. This seems technically possible, and the report shows believable results. However, the description of the method is not clearly described. There is no description of what ancillary inputs are required to perform planar homography (presumably altitude and orientation?), so that	

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2. Quantification of Slick Area:	
these requirements could be considered in the context of an at-sea operation. Information regarding how the presence or absence of fire is detected is inadequate. Information provided subsequent to the draft report suggests that a simple threshold was used to detect pixels containing fire, but potential difficulties related to lighting conditions, water surface reflections, or other potentially confounding issues were not addressed in the report.	
2.2–Are the numbers of images, heights, and angles from around the fire adequate for accurate area computations using the photogrammetric methods reported? Explain how the approach chosen could affect the validity of the methodology and results.	
The report demonstrates believable results with three images, so perhaps this is sufficient. The report does not describe any efforts to examine how the results change as a function of the number of images, or their locations. Given that there were more than three images used, it is possible to at least begin such an investigation. A fuller analysis that examines changes with number of images, height of images, and angles of images would be desirable.	
2.3–Does the report adequately address the methods to account for errors from obstructions and limited angles/heights/distances? Explain how the methods used to account for errors could affect the validity or scientific merit of the methodology and results.	
The issue with occlusion due to obstructions appears to be adequately solved with images from multiple angles around the fire. A greater issue seems to be dealing with smoke, which the report describes as being problematic for both the visual and infrared cameras. Examining the photographs of ISBs shown in Figure 1 of the report, the challenge would appear to be billowing smoke when wind is present (see the third panel of Figure 1). The billowing smoke issue would appear to be a difficult problem to overcome using the present methods. A greater investigation of the use of IR – perhaps one that identifies a specific IR wavelength – seems warranted.	
2.4–Are the assumptions of the area algorithm input with respect to burning area of the slick clearly defined and appropriate (see Sections 2.1.1, 3.1.1, and 3.2.1)? If yes, explain why. If not, explain how those assumptions could be defined more clearly. Provide a rationale for your answer about the appropriateness of the assumptions of the area algorithm input with respect to burning area of the slick.	
It is difficult to answer this question without more detailed knowledge about the fire detection algorithm (step 6 above section 2.2) or examples of how an external length scale such as a boom are used to quantify the area (step 8 above section 2.2).	
2.5–What are the strengths and weaknesses of the methods for the determination of the area(s) of the burning slick? Provide a rationale for each identified strength or weakness.	
The main strength of the approach is the simplicity of the measurement – camera images are routinely collected using manned aircraft and drones at sea, they have been used previously to measure the sizes of objects, and it seems that this technology could be readily applied to the problem of ISBs.	

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NAME: Dr. Thomas Weber	**AFFILIATION: University of New Hampshire**
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2. Quantification of Slick Area:	
The main weakness seems to be obscuring of the burn area by blowing, billowing smoke, as can be seen in some of the example ISBs shown in the introduction. Cameras can't measure what they can't see and, according to the report, this issue is present even for cameras operating at infrared wavelengths. If present, billowing smoke could cause large biases in the estimates of area. These seem to be solvable problems, but remain largely unaddressed in the draft report.	

5.4.3 BSEE Study Report Charge Questions

Quantitative Measurement of *In-Situ* Burn (ISB) Efficiency and Rate	
NAME: Dr. Thomas Weber	**AFFILIATION: University of New Hampshire**
DATE: 12/29/2017	
3. BSEE Study Report:	
3.1–To demonstrate the technology proof of concept—Does the report adequately address the methodology to accurately calculate the volume of the entire slick given the differences in thicknesses throughout the entire slick being burned? Explain how this affects the validity or scientific merit of the methodology and results.	
There are gaps in the methodology that need to be addressed for making these measurements in a laboratory setting. In terms of the acoustically-derived thickness measurement, the measurement of the temperature profile of the oil needs to be refined. Of particular importance is determining the height of the upper layer of the oil (that is, the location of the oil/flame interface). This seems to be done only visually at the present time, and the results are not self-consistent (the time-varying height of the oil/flame interface used to generate the temperature profiles does not match the acoustic thickness measurement). A methodology needs to be established for doing this with greater accuracy, and an uncertainty for this methodology needs to be established. The issue of determining a temperature profile is compounded by the potential for spatial variability in slick thickness. This was unaddressed in the laboratory setting, although it appears that the experimental setup would lend itself to such an investigation. To advance this method beyond a laboratory setting would require deploying sensors under the slick, in the case of the acoustic measurement, or in the slick to determine the temperature profile. The latter leads to an apparent basic flaw in the measurement: measuring the temperature profile requires knowledge of the slick boundaries (or at least the upper boundary), which implies that the slick thickness may be known before the acoustic measurement is performed. That there is no currently accepted method for making such a temperature profile measurement is certainly a limitation on the proposed acoustic methodology described in the draft report.	

Quantitative Measurement of *In-Situ* Burn (ISB) Efficiency and Rate

NAME: Dr. Thomas Weber | **AFFILIATION: University of New Hampshire**

DATE: 12/29/2017

3. BSEE Study Report:

Given the way in which oil is boomed to facilitate burning, it seems very likely that there will be large spatial variations in slick thickness. Operationally, the acoustic and temperature sensors would have to be deployed on an underwater vehicle – presumably an ROV or an AUV. This has not been addressed in the report, but likely would present a large operational challenge given the difficulties in deploying such sensors under the ocean under quiescent conditions. The high acoustic frequencies used in the proposed methodology would require very short range measurement (several meters, presumably), which places a vehicle only a few meters underneath an ignited burn. This would seem to create significant risk to the vehicle, its tether, etc.

3.2–To demonstrate the technology proof of concept—Does the report describe with reasonable accuracy how burn volumes, burn rates, and burn efficiencies are computed? If yes, explain why these computations are described with reasonable accuracy. If not, how could the report describe these computations more clearly or with improved accuracy?

Determining the accuracy of these measurements in the lab requires a valid benchmark. The benchmarking has been inadequately described in this report. The benchmark used relies on converting the mass of the oil to its volume, and dividing the volume by the cross-sectional area of the burn container. The conversion of mass to volume requires the density, which is a function of temperature, and as shown the temperature is not constant throughout the oil layer. The report also quotes a density-temperature relationship, which is unreferenced. The report does not describe how the spatially (at least vertically) varying and time-varying temperature of the oil was used to find a density.

Beyond benchmarking in the lab, extension of this methodology to the field would require an uncertainty analysis (e.g., propagation of error) on the methods. This has not been undertaken, nor are there any estimates of the uncertainty in the individual components (e.g., arrival time, sound speed, pixel flame detection).

3.3–To demonstrate the technology proof of concept—Are the limitations and uncertainties clearly identified and adequately characterized for the determination of burn volumes, burn rates, and burn efficiencies? If yes, explain why. If not, how could the limitations and uncertainties for the determination of burn volumes, burn rates, and burn efficiencies be described more clearly or characterized with improved accuracy?

No, the report does not adequately describe or identify the limitations and potential pitfalls of the proposed methodology.

The most fundamental limitation for extending this method to a field environment is dynamic nature of ISBs, as discussed during the panel review with ISB experts, where oil is entering the boom as it is towed. Two factors will change the thickness: the amount entering and the amount being burned off; but only one factor affects the burn rate: the amount being burned off. Thus, measuring the thickness alone without knowledge of the amount entering is insufficient for estimating the burn rate.

Quantitative Measurement of *In-Situ* Burn (ISB) Efficiency and Rate	
NAME: Dr. Thomas Weber	**AFFILIATION: University of New Hampshire**
DATE: 12/29/2017	
3. BSEE Study Report:	
Another fundamental limitation is the need for knowledge of the sound speed of the oil. This requires knowledge of the oil temperature profile, for which there is no established method in the field, but it also requires knowledge of the temperature-dependent sound speed. Current methods for establishing this sound speed require empirical testing with oil samples. How this can be done for oil that has been weathered at the surface, or turned into an emulsion, is unclear and has not been addressed in the report.	
3.4–To demonstrate the technology proof of concept—What are the strengths or weaknesses of the methods used for the computations? Provide a rationale for each identified strength or weakness.	
In a static laboratory setting, the formula used for estimating ISB burn rate should be sufficient, as long as complete knowledge of the parameters can be had (this is of significant concern, however, as noted above). This formulation is for a closed system, where no oil is added. In an operational environment, where oil booming continues during burning, the formulation no longer applies and the rate of change of thickness no longer becomes a direct estimate of burn rate. The formulation would need to be changed to quantify the amount of oil entering the burn and, presumably, its spatial variability.	
3.5–To demonstrate the technology proof of concept—Are there any other conclusions that could be drawn that are not adequately addressed in the report? Are there any other issues or concerns with the validity of the methodology or results that were not included in the previous charge questions?	
The report demonstrates what has been previously shown in the literature: sound waves reflect from oil/water and oil/gas interfaces, and if knowledge of the sound speed is in-hand these reflections can be used to determine a layer thickness. The authors demonstrate an ability to make such measurements with a resolution of a mm, or perhaps a few mm. More advanced methods (e.g., broadband pulses) could likely be used to increase this resolution (this technique was employed by Bassett et al., 2015), who used lower-frequencies but broadband pulses). Such methods might be useful for looking at slick and/or emulsion thickness when the oil temperature is constrained (i.e., not during an ISB) to great effect.	

6. APPENDIX B: PANEL MEETING MINUTES

FINAL

Minutes of Peer Review Panel Meeting

December 11-12, 2017

For the BSEE study:

Quantitative Measurement of In-Situ Burn (ISB) Efficiency and Rate

January 17, 2018

Prepared by:
EnDyna, Inc.

BSEE Contract Number: BPA E14PA00008
Task Order Number: E17PB00070
(Task Order 10)

6.1 Introduction

EnDyna selected a peer review panel of four senior scientists with expertise in: 1) *in-situ* burning (ISB) in open water conditions, 2) acoustic measurement, and 3) photogrammetric measurement techniques. Each peer reviewer prepared initial written comments on the draft final report entitled, *Quantitative Measurement of In-Situ Burn (ISB) Efficiency and Rate*. The peer reviewers submitted their initial written comments to EnDyna prior to the December 11-12, 2017 peer review panel meeting. EnDyna compiled these initial written comments and distributed the compiled initial written comments to all peer reviewers on December 4, 2017 for review prior to the peer review panel meeting.

The peer review panel meeting was held on December 11-12, 2017 at EnDyna's office in McLean, Virginia. Section 6.2 presents the minutes for the peer review panel meeting. Section 6.3 presents the agenda for the peer review panel meeting.

To facilitate obtaining as much information as possible prior to the panel meeting, EnDyna's Peer Review Lead analyzed each of the reviewer's initial written comments, and listed/paraphrased the peer reviewer's questions about the draft final report. EnDyna provided BSEE a list of the peer reviewer's questions in four batches, with the identity of each peer reviewer kept anonymous. EnDyna requested that BSEE provide answers to these peer reviewer questions in writing so that EnDyna could distribute written answers to all four peer reviewers in advance of the peer review panel meeting. Section 7 (Appendix C) presents BSEE's written answers to the peer reviewer questions re-organized by charge question and reformatted in a more readable manner. EnDyna distributed BSEE's written answers to the peer reviewer questions to all four reviewers on December 7, 2017.

The objective and scope of this peer review are summarized below, as outlined in the peer review charge document provided to the peer reviewers. In addition, the "ground rules" for the peer review meeting are outlined below.

6.1.1 Peer Review Objective and Scope

The objective of this panel-style peer review is for BSEE to receive comments from individual experts on the draft final report entitled, *Quantitative Measurement of In-Situ Burn (ISB) Efficiency and Rate*. This panel-style peer review was technical in nature, reviewing the methods, data quality, the strengths of any inferences made, and the overall strengths and limitations of the study.

BSEE Charge for the Scope of this Peer Review
BSEE had carefully defined the scope of this peer review for the draft final report in order to focus the peer review process effectively on BSEE's Charge Questions. The peer reviewers were directed to keep their written comments within the BSEE scope defined below. It is important to remember that this panel-style peer review was technical in nature, reviewing the methods, data quality, the strengths of any inferences made, and the overall strengths and limitations of the study.

The scope of the peer review is focused on the methodology used in this study to determine burn volumes, burn rate, and burn efficiency. As such, the peer reviewers should focus on providing comments on the technical nature of the report. Because the review is technical in nature, the peer reviewers should not focus on editorial style.

6.1.2 Peer Review Panel Meeting "Ground Rules"

The "ground rules" provided to the peer reviewers both prior to and during the peer review panel meeting are listed below:

- An external peer review is intended to solicit individual reviewer feedback, to increase the independence of the review process.
- The panel is not asked to, and should not attempt to, form consensus or collective recommendations, ratings, or opinions, and panel reviewers must understand that they should provide individual feedback on the research product.
- Any BSEE staff that may attend the panel meeting can only provide background information on the research product to the peer reviewers, which can occur only during the panel meeting run by EnDyna, and at EnDyna's request.
- The panel meeting will not include discussion related to BSEE policy recommendations and decisions.

6.2 Peer Review Panel Meeting Minutes

The peer review panel meeting was held on December 11-12, 2017 at EnDyna's office in McLean, Virginia. This section presents the minutes that summarize the discussion at the panel meeting.

Attendees:
Ms. Amy Doll, EnDyna, Peer Review Lead
Mr. Ken Rock, EnDyna, Facilitator
Dr. Oscar Garcia-Pineda, Expert Peer Reviewer
Dr. Bill Lehr, Expert Peer Reviewer
Mr. Neré Mabile, Expert Peer Reviewer
Dr. Tom Weber, Expert Peer Reviewer

Presenter (Background on BSEE Study):
Ms. Karen Stone, BSEE, Oil Spill Response Engineer

6.2.1 Day-1: December 11, 2017

Dr. Smita Siddhanti, President of EnDyna, opened Day-1 of the panel meeting at 8:30am by introducing EnDyna's Facilitator, Mr. Rock. All of the attendees and the presenter introduced themselves and provided some brief background on their expertise.

Mr. Rock reviewed the "ground rules" for the peer review panel meeting (see Section 6.1.2). Ms. Doll briefly reminded the peer reviewers about the process and schedule for submitting final written peer review comments after the panel meeting.

BSEE Background Information Presentation

Ms. Karen Stone made her presentation, "Quantification of *In-Situ* Burn (ISB) Rate and Volume," to provide useful background on the BSEE study entitled, *Quantitative Measurement of In-Situ Burn (ISB) Efficiency and Rate*. BSEE's Oil Spill Division developed Technology Readiness Levels

(TRLs) through a large workshop that included industry and federal government representatives. Ms. Stone quickly reviewed all of BSEE's TRLs from 1-9 as presented in the chart below.

Ms. Stone explained that this research project under peer review is at the technology **proof of concept** level, or more specifically at TRL-3. She mentioned that TRLs 4-6 include starting to "breadboard" a technology and building a prototype. More information on BSEE TRLs can be found on the Research Project OSRR-1042 webpage on BSEE's website. Ms. Stone also mentioned that BSEE works with the Interagency Coordinating Committee on Oil Pollution Research (ICCOPR), along with other federal agencies.

The Oil Pollution Act of 1990 (OPA 90) and Executive Order 12777 (EO 12777) provide the authorities for both onshore and offshore oil spill response planning and oil spill response in the United States. Regulations on offshore oil spill preparedness were promulgated in 1997 to implement the new BSEE authorities.

TRL	Brief Description	Detailed Description
		Technology Research and Development
1	Basic principles observed or reported	Basic scientific exploration of relevant biology, chemistry, or physics begins and leads to enhanced knowledge for a relevant subject area.
2	Technology concept and speculative application formulated	The technology concept has been formulated and the potential broad class of spill response applications has been identified. Preliminary data generated.
3	Technology proof of concept demonstrated	The proof of concept of the relevant biological, chemical, or physical, principles or techniques has been shown and reproduced on a relevant hydrocarbon product on a laboratory scale or model data generated for a specific scenario.
		Technology Advancement, Development, and Demonstration
4	Technology prototype demonstrated in laboratory environment or model scenario	A prototype of the technology has been demonstrated in a laboratory environment. The prototype is advanced over the proof of concept either by hardware, software, and/or with reproducible data generated for specific scenarios on relevant hydrocarbon products or applications.
5	Technology prototype tested in relevant environments	A prototype of the technology with increased fidelity has been demonstrated in relevant environments. Accuracy and precision of the results have been documented. Model data validated with experiments.
6	Full scale prototype demonstrated in relevant environments	A prototype of the technology has been demonstrated in relevant environments. The prototype is advanced over the proof of concept either in component integration, fidelity of the hardware or software, or with experimental or model data generated for specific scenarios to show applicability. Regulatory approvals and industry standards considered.
		Technology Implementation in Operational Environments
7	Integrated technology tested on a large scale or in open water	Full scale prototype integrated into intended operating system and tested on a simulated spill, in a relevant environment, in open water, or in a real spill environment. Intended operator is identified and system has been beta tested by others. Data analysis or interpretation becomes automated.
8	Final integrated system tested in real or relevant environment	The final integrated system has been proven to function in real or relevant environment with performance and operational specifications and limitations defined. Reproducible data to support claims has been documented in publically available publications. The technology is ready for spills of opportunity and field use.
		Technology Deployment in Real Spill Environment
9	Final integrated system deployed in real spill environment	Technology has been successfully operated on an intentional or unintentional spill in a real spill environment by the intended operator and meets the technology claims. Training, supporting documents including a user manual and any independent verification or certifications are included.

As a brief overview of oil spill response countermeasures, Ms. Stone noted that there are three universally accepted response countermeasures for offshore oil spills—mechanical recovery, ISB, and the use of dispersants. Other technologies, such as remote sensing, common operating procedures, and modeling also exist to support oil spill response decision-making and help optimize the use of the different countermeasures. Ms. Stone emphasized that the success of an offshore oil spill response depends on the efficiencies of these technologies. BSEE's Oil Spill Preparedness Division (OSPD) supports the use of the best available and safest technologies by continuing to advance existing technologies, identifying emerging technologies, and integrating the two. Ms. Stone presented several photographs of ISB in open water conditions.

Ms. Stone explained that for oil budget calculations, federal agencies need to know how thick the oil spill is and how much oil is removed using different countermeasures. Burn volume estimation generally involves the following calculation: estimated burn area x burn duration x burn rate. In actual oil spill responses, the graphs and worksheets to make such calculations are more complex.

Mr. Mabile remarked that for the Deepwater Horizon (DWH) oil spill, ISB occurred outside of those areas where mechanical recovery was conducted. For burn volume estimation during DWH, he contacted experts/laboratories, obtained data on burn rates, and determined that 0.05 to 0.08 gpm/ft^2 (gallons per minute per square foot) was the most practical number to use for DWH calculations. This range accounted for the various weathered oil properties collected within towed ISB boom systems, which contained a combination of fresher oil and emulsified oil. Mr. Mabile explained that when there was up to 50% water in emulsified oil, then it was practically impossible to ignite even with accelerants. He also explained that about 5 days after the Macondo well was successfully capped, weathering and emulsification occurred, and a slick could not be ignited. The DWH Unified Command (UC) decided that the DWH ISB Team should not be concerned about residue, but should focus on burning as much oil as possible to prevent spilled oil from reaching the shoreline. Mr. Mabile stated that the DWH ISB Team had demonstrated as much as 60-70 thousand barrels of spilled oil could be burned in one day, when the seas were very calm.

Ms. Stone discussed that BSEE had issued a Broad Agency Announcement (BAA) for white papers on quantifying ISB efficiency. The BAA was issued because ISB had proven to be an effective response tool during past oil spills and may be an effective means of remediating crude oil on water in the Arctic. The BAA stated that concepts and/or development of new tools to quantify the efficiency and amount of oil remediated by these burns would be evaluated under this topic.

BSEE received 30 white papers in response to this BAA. After forming a technical advisory committee, BSEE selected five for proposals. From the five proposals received, BSEE funded Applied Research Associates (ARA) for this BSEE study entitled, *Quantitative Measurement of In-Situ Burn (ISB) Efficiency and Rate*.

Ms. Stone emphasized that this was a **proof of concept** study. The study's objective was to develop and test methods to directly measure the volume of oil burned and the burn rate in real time during ISB by integrating the direct thickness measurements using acoustic methods and surface area measurements derived from visible and infrared images. The longer-term goal is to evaluate these methods for ISB in open water conditions. Ms. Stone reviewed the tasks for this study:

Task 1: Acoustic thickness measurement of burning oil:

- Determine the speed of sound gradient as a function of temperature.
- Determine the effects of surface modulations caused by waves from various sea states or turbulence produced during burning operations.
- Measure thickness as a function of time.

Task 2: Image Analysis:

- Develop image processing algorithms to improve the accuracy of surface area measurements that will be investigated to enable rapid, automated measurements including the effect of waves on the surface area measurements.
- Measure surface area of the burning oil as a function of time.

Task 3: System Integration:

- Integrate thickness and surface area measurements to calculate the burn efficiency and rate in real time.

Task 4: ISB at Worcester Polytechnic Institute:

- Test the methods developed in the preceding tasks on larger-scale burns (1 meter diameter burn pans).

Task 5: ISB at the United States Army's Cold Regions Research and Engineering Laboratory (CRREL):

- Perform tests to further develop the methods to measure ISB efficiency and rate on oil in ice in an outdoor facility.

Ms. Stone concluded her presentation by stating that ARA was developing a tool to identify the interface of the flames and the oil on water, using regular cameras and infrared cameras.

Background DWH ISB Video

As requested by EnDyna’s Peer Review Lead, Mr. Mabile presented a video of ISB operations during DWH, and there was a general discussion among the reviewers about how this video demonstrated actual operations for ISB in offshore open water conditions.

General Impressions: *Overall impressions addressing the accuracy of information presented, clarity of presentation, and soundness of conclusions*

Mr. Rock asked each reviewer to use around five minutes to provide a high-level summary of their general impressions for the BSEE study entitled, *Quantitative Measurement of In-Situ Burn (ISB) Efficiency and Rate*.

Dr. Weber stated that the draft final report was well organized into sections that focus on the two basic measurement techniques (area and thickness). He expressed concerns that the technical content often lacked sufficient detail and the assumptions were buried, which made it difficult to conduct a full technical review.

Dr. Weber had some basic questions about the objectives of the study and stated that it seemed a simple approach that generally used tried and proven basic methods. Dr. Weber stated the major issue he identified with the draft final report was the need to know the vertical temperature gradient of the oil in order to convert measurements of acoustic travel time to distance in order to measure slick thickness. He emphasized that the vertical temperature/sound speed gradient will be difficult to obtain, because there is such a huge gradient ranging from burning oil at over 1000°C to ocean water temperatures and with varying thicknesses throughout a slick. Dr. Weber explained that determining the vertical temperature gradient of the oil is essential to use acoustic methods to measure slick thickness. It also is important to understand how temperature is related to sound speed.

With respect to measuring slick area, Dr. Weber expressed concerns about smoke obscuration and the technical hurdles of demarcation between the fire and smoke. Dr. Weber concluded by suggesting the slick area could be measured by putting the cameras on aircraft that are already flying over spilled oil (to make visual estimates currently used) during responses, and this could achieve a similar result without the use of drones.

Mr. Mabile was excited that research was being conducted on methods to calculate a more accurate burn volume for oil removed by ISB. He expressed concerns that the study spent too much effort on validating the burn rate, and noted that oil burn rates are well established from research conducted many times over several decades. Mr. Mabile stated that emulsions are important, and suggested that it would be more relevant to conduct research about acoustically measuring the speed of sound through varied oil emulsion thicknesses. Because actual ISB operations in offshore open water conditions would typically not be collecting fresh oil, he thought laboratory ISB experiments should be conducted instead on emulsions because actual ISB operations in offshore open water conditions will primarily collect emulsified oil in ISB boom systems. Mr. Mabile expressed concerns that the draft final report did not include much information on the accuracy of measurements from the laboratory ISB experiments.

Mr. Mabile disagreed with the TRL level indicated in the draft final report, and stated that this study was only a partial simulation of ISB operations especially because no emulsions were evaluated in the laboratory ISB experiments. Overall, Mr. Mabile was impressed with the effort but emphasized that there was a huge jump needed to make this research applicable to actual ISB operations in offshore open water conditions. Mr. Mabile concluded by noting that the photogrammetry techniques used in the study are not new and can already be implemented; however, more work is needed to apply those techniques to fire area estimation during actual ISB operations in offshore open water conditions.

Ms. Stone asked Mr. Rock whether she could provide additional background information. Ms. Stone stated that evaluating the potential for using this study's methodology for actual ISB operations in offshore open water conditions was out-of-scope. Ms. Doll, EnDyna's Peer Review Lead, noted that the BSEE COR (Ms. Stone) had specifically requested expertise with ISB in open water conditions for this peer review, instead of expertise with ISB in laboratory experiments.[5]

Dr. Lehr began by stating that the degree of accuracy needed depends on the purpose of the method. He explained that for oil spill responses it is important that measurements are accurate enough to influence decision-makers. Dr. Lehr noted that for DWH, the oil removal measurements for ISB were more accurate than the oil treatment measurements for dispersants. He emphasized that measurements in the field are much more difficult than laboratory experiments, and the logistics of field operations must be considered. Dr. Lehr was excited about the potential use of acoustics and believed it may be possible to use acoustics to obtain reasonable accuracy to measure slick thickness.

[5] Mr. Mabile and Dr. Lehr were selected as peer reviewers because of their expertise with ISB in open water conditions.

For slick area measurements through mapping of surface area by visual and infrared cameras, Dr. Lehr was concerned that large amounts of black smoke may affect accuracy or lead to failure during actual ISB operations in offshore open water conditions. Dr. Lehr emphasized that his major concern with the method used in the study was how much emulsions would affect the results in measuring oil removed by ISB. He stated that emulsions may affect the results more than issues quantifying the fire area through obscuring smoke. Dr. Lehr concluded by emphasizing again that the necessary degree of accuracy depends on what decision-makers need during oil spill responses.

Dr. Garcia-Pineda stated that the draft final report lacked technical detail, but he was impressed with the innovative science involved in the laboratory ISB experiments for slick thickness measurements. Dr. Garcia-Pineda expressed concerns about the lack of information on calibration for the laboratory ISB experiments. Dr. Garcia-Pineda also expressed concerns about whether the study had included any repetition and verification of results for the techniques for slick thickness measurements with the acoustic system. With respect to measurement of the slick area, he emphasized that much more technical detail on the image processing algorithm and image rectification technique was needed in order to evaluate the photogrammetry techniques used in the laboratory ISB experiments. Dr. Garcia-Pineda concluded by noting that this is a difficult subject and the study seemed to offer a promising approach that may have practical potential.

Charge Question 1.1: Are the methods used to measure the oil slick thickness throughout the entire length of the *in-situ* burn tests valid? If yes, explain why these methods are valid. If not, how could the validity of the oil slick thickness measurement methods be improved or more clearly described?

Dr. Weber explained that using an acoustic method or more generally an “echo sounding” principle to measure oil thickness is not a new idea and noted that Dr. Chris Bassett, et. al., already has several publications with results for similar research (e.g., Journal of the Acoustical Society of America 137(1), EL32-EL38, 2015). Dr. Weber emphasized that acoustic travel time should be measured using harmonic mean sound speed because ISB has a large temperature gradient. Although it was not clear in the draft final report, he stated that BSEE’s written answers to the peer reviewer questions (see Section 7 (Appendix C)) clarified that the study did <u>not</u> use harmonic mean sound speed.

Dr. Weber explained that the acoustic measurement in the draft final report may seem simple conceptually, but emphasized that the difficulty with the approach used in the study is obtaining adequate information about the temperature gradient for the burning oil slick. He drew a diagram as a general illustration of how the temperature at the top of the burning slick will be very hot while at the bottom of the slick on the ocean water it will be cold. Dr. Weber believed that the sound speed gradient and the temperature gradient will be highly variable. Dr. Weber explained that it is necessary to measure temperature gradients in order to measure harmonic mean sound speed. He stated that it would be necessary to place thermocouples up into the oil slick, and questioned whether there might be a more sensible method to measure slick thickness.

Dr. Weber explained that the sound speed in oil is a strong function of the temperature gradient. He also explained that the sound speed in oil will vary for different types of oils. Dr. Weber stated that the draft final report included an incorrect statement that “the speed of sound in a fluid is directly related to the viscosity"—and emphasized that sound speed is typically considered to depend on the bulk modulus and density instead, and not the viscosity. Dr. Weber added that other factors will affect the sound speed in oil, including the amount of oil weathering, where the oil has been, and how quickly VOCs get stripped off. Because the temperature and speed of sound will vary hugely, Dr. Weber believed that the errors will be large with this acoustic measurement method.

Dr. Weber stated that at some point during ISB, the oil/water interface will become very complicated and it will become a very dynamic (rough) interface. He stated that the draft final report seemed to include "a lot of averaging" because the interface shown in the draft final report was smooth. He noted that the acoustic data/results from the laboratory ISB experiments were "very noisy" and emphasized that was not explained in the draft final report. Dr. Weber also mentioned that the speed of sound will be different in oil/water emulsions. For emulsions, he explained it would be necessary to measure the speed of sound for individual constituents and also to calculate them together.

Dr. Garcia-Pineda believed that the acoustic method to measure oil slick thickness was valid, but emphasized that the draft final report lacked information on how the results were achieved. He mentioned that other methods are available to measure oil thickness. Dr. Garcia-Pineda stated that the draft final report needed information on calibration tests for the acoustic measurement system. He wanted to see how the researchers replicated control points to test the study's acoustic system for calibration. Dr. Garcia-Pineda also wanted to see a comparison of the results from the series of burn tests for the laboratory ISB experiments, which he thought would be helpful in understanding whether the burn test results were well correlated for burn tests done under similar circumstances. He noted that other methods to measure thickness could be used if the method described in this report was not practical. Dr. Garcia-Pineda stated he was about to publish a paper with the National Oceanic and Atmospheric Administration (NOAA) that describes three ways to measure oil thickness.

Dr. Lehr stated that the basic physics for using acoustic impedance to measure oil slick thickness seemed straightforward. Based on his experience, he anticipated that such acoustic measurements for an oil-air interface may be more challenging than for an oil-water or oil-ice interface. Dr. Lehr emphasized that an actual oil spill in open water conditions will have a moving surface. Dr. Lehr explained that the accuracy he had estimated from the draft final report was a minimum measurable oil thickness of around 1mm, and stated that his estimated 1mm accuracy would probably be adequate for ISB because oil thinner than 1mm would not sustain a burn. Dr. Lehr expressed concerns about how the acoustic method would work for the oil-water interface in situations where boiling water occurred under a burning slick, but acknowledged that probably would not happen in open water conditions.

Dr. Lehr observed that the accuracy of the acoustic measurement method seemed to decrease as the temperature increased in the laboratory ISB experiments. He also noted that the uncertainty and errors are not clearly described in the draft final report.

Mr. Mabile stated that measuring the speed of sound with emulsions would represent totally different challenges than the fresh oil used in the laboratory ISB experiments. He noted that the temperature profile of burning oil may not be as great in open water conditions as some might think. He mentioned a Newfoundland ISB report for a study that used submarines underneath the burning slick. Mr. Mabile stated that previous research has shown the minimum oil thickness to sustain combustion for ISB is 2mm and this requirement is the reason that oil is collected in an ISB boom system. He noted that data from the study indicated that the burn stopped when the measured slick thickness reached 2mm, which correlated well with many previous laboratory tests.

Mr. Mabile also stated that for ISB in offshore open water conditions there is always boiling and often water is shooting up into the fire, which are situations that he believed would create background noise that would affect acoustic measurement. He mentioned that the oil/water interface during ISB can be noisy—like bacon sizzling. Mr. Mabile also stated that varying emulsions in oil slicks would also affect acoustic measurement.

Ms. Stone asked Mr. Rock whether she could provide additional background information. Ms. Stone explained that emulsions would be way up BSEE's TRL ladder, and that the researchers for this study were analyzing fresh unweathered oil. Additional research on emulsions is planned in the future.

Mr. Rock asked for discussion about charge question 1.1. Dr. Lehr asked Dr. Weber to provide additional information to explain the differences in the speed of sound between water and oil. Dr. Weber pointed to Figure 18 in the draft final report (page 22) and provided additional explanation. Dr. Weber added that the moving surface is not much of an issue for the speed of sound. Dr. Garcia-Pineda asked whether changing angles would affect the acoustic measurement of thickness, because he expected the slope would affect the beam. Dr. Weber stated that the beam must be close to the slick, and that if using a wide beam then changing angles would probably not be a major technological hurdle.

Dr. Lehr asked Mr. Mabile for clarification about whether boiling occurred for ISB on large slicks during DWH, and Mr. Mabile replied yes. Ms. Stone mentioned that during DWH emulsions were breaking down from the heat during ISB and this emulsion breakdown process could be heard by responders. Ms. Stone added that during the laboratory ISB experiments for this study the water below the oil was boiling. Dr. Lehr noted that what was occurring is called a "rapid phase transition."

Dr. Weber explained that two interfaces are involved in measuring the speed of sound: 1) the bottom of the slick, and 2) the top of the slick. He also explained that if emulsions were breaking down from the heat that would create a major problem in identifying the top of the slick. Mr. Mabile asked how the background noises typically heard during ISB in open water conditions would affect the signal-to-noise ratio and acoustic measurements. Dr. Weber explained that the human ear can only hear sounds at lower frequencies, which he emphasized are at a much lower frequency than the MHz frequencies discussed in the draft final report.

Mr. Mabile explained that typically during oil spill response, by the time that ISB gets approval, responders would probably be dealing mainly with emulsions and not fresh oil. He added that an exception might be the case of an "accidental" burn such as a tanker spill that ignites on its own.

Dr. Weber pointed to Figure 15 in the draft final report (page 20), and stated that it showed a very steep temperature profile over 2mm. Mr. Mabile drew a diagram to illustrate a typical oil slick thickness profile within a towed ISB boom system. He exemplified that if the slick at the boom apex has 20-24 inches of oil, the temperature gradient will be important because at the 20-24 inch thickness, all of the oil will be burning until the slick diminishes to less than 2mm in thickness. Mr. Mabile stated again that previous research demonstrated 2mm is the minimum oil thickness to sustain combustion for ISB, which is the reason that oil is collected in an ISB boom system.

Mr. Mabile also explained that from the air, responders can easily distinguish the thicker fresh oil from emulsions and sheens. Dr. Garcia-Pineda added that from the air, it is possible to observe the “aspect,” or darkness, of the oil. Mr. Mabile noted that ISB operations during DWH used two aircraft. Dr. Garcia-Pineda explained that observations from the air can only see what is on the surface and it is not possible to estimate slick thickness from the air by the aspect of the oil. Aspect (darkness) indicates the oil is fresher and easier to burn, but will not indicate thickness.

For clarification, Dr. Weber asked whether knowing the exact slick thickness is helpful operationally during ISB in open water conditions. Mr. Mabile indicated slick thickness would not necessarily be helpful. Dr. Weber asked for clarification that no optimization regarding slick thickness was necessary for ISB operations. Ms. Stone mentioned that the USCG would say that thickness is important information for boats/vessels towing the ISB boom systems. The USCG would like to report thickness data to vessel operators because that would indicate whether vessels should slow down or speed up. Dr. Lehr mentioned that the USCG needed information for their ICS-209 Incident Status Summary Forms.

Mr. Mabile stated that the most important question for ISB operations in offshore open water conditions is determining the slick location for directing ISB resources effectively. Dr. Weber asked whether the most important ISB operational question might instead be where the thickest oil is located.

Dr. Garcia-Pineda stated that the upper layer (no deeper than 1mm) of oil is what can be seen from the air during reconnaissance, but emphasized that the oil below the upper layer may be different. He mentioned again that it is not possible to estimate the thickness of oil contained within an ISB boom system or the thickness of denser oil slicks from the air. For a thin oil layer (less than 500 µm), it is possible to estimate thickness from the air based on best professional judgment about its aspect.

Mr. Mabile clarified that operationally the most significant information for ISB in open water conditions is the ability to measure the exact area of the fire over time on a continuous basis. He emphasized that the oil slick thickness within an ISB boom system will vary significantly.

Dr. Garcia-Pineda questioned whether the cameras used in the study may have had properties to measure temperature that would allow data collection through the surface of the oil.

Dr. Weber reminded everyone that Mr. Mabile stated that ISB operations had occurred the furthest out from the source of the oil spill during DWH, compared to other oil spill response countermeasures (dispersants, mechanical recovery). Mr. Mabile explained that the DWH ISB operations were removing 2-3 day-old oil most of the time, because it was further from the source of the oil spill.

Dr. Weber asked Dr. Lehr about the accuracy needed for decision-makers for ISB operations. Dr. Lehr noted that previous research studies already provide documentation of oil burning rates. Dr. Weber asked Dr. Lehr whether a factor of five (5) would be sufficient accuracy for ISB operations. Some general discussion among the reviewers followed about the question of whether acoustic measurement of oil slick thickness would be most useful for planning ISB operations or for calculating the oil budget during an oil spill response.

Charge Question 1.2: Is the method to quantify the speed of sound in oil during *in-situ* burning operations valid? If yes, explain why the method is valid. If not, how could the validity of the speed of sound in oil quantification method be improved or more clearly described?

Mr. Mabile stated he was not sure that the calibration was accurate for the laboratory ISB experiments and noted that validation and calibration information was not provided in the draft final report. He was not sure how calibration could be accomplished accurately with the variable heat range through the slick under the fire. Mr. Mabile noted that during ISB in open water conditions, widely varying temperature profiles will occur throughout the oil slick inside an ISB boom system especially with a large fire. Mr. Mabile believed that such widely varying temperature profiles throughout a slick will make it difficult to quantify the speed of sound accurately. Other factors, such as varying slick densities with emulsions and winds and hot air drafts, will occur with very large burns. Overall, Mr. Mabile thought the objective of making any real-time measurement of oil slick thickness seemed far-fetched during ISB operations in offshore open water conditions.

Dr. Weber stated that using themocouples to quantify the speed of sound was OK in the laboratory-constrained environment for the laboratory ISB experiments where the temperature range was limited and the oil composition was consistent. Dr. Weber commented that for surfacing oil that has weathered and lost some of its carbon chains, it may not be possible to transfer this laboratory approach for sound speed measurements to ISB in open water conditions because such changes in oil composition could change the sound speed of the oil. He questioned whether igniting the oil would greatly accelerate changes in oil composition.

Ms. Stone asked Mr. Rock whether she could provide additional background information. She explained research has shown that oil properties stay constant during ISB.

Dr. Garcia-Pineda stated that he had nothing to add with respect to this charge question.

Dr. Lehr mentioned that NOAA models will indicate the current state of oil weathering during oil spill responses. These NOAA modeling results will probably estimate oil weathering within the degree of accuracy needed for planning ISB operations. Dr. Lehr stated that he believed the method presented in the draft final report to quantify the speed of sound in oil during ISB may be accurate enough for the purposes of planning ISB operations.

Mr. Mabile stated that decades of research have established the burn rates of many different types of oil. He explained that, in general, for crude oil the estimated burn rate range is 0.05 to 0.08 gpm/ft^2 (gallons per minute per square foot). Mr. Mabile explained that this range was used for DWH ISB operations. Even though the government decision-makers asked for a point estimate, he always provided this estimated range instead of one number.

Dr. Garcia-Pineda commented that the method presented in the draft final report to quantify the speed of sound in oil was OK for laboratory ISB experiments.

Charge Question 1.3: Does the report adequately address the measurement of varying slick thickness throughout the entire slick? If yes, explain why this measurement is adequately addressed. If not, how could these measurements be improved or more clearly described?

Dr. Garcia-Pineda noted that from a common sense perspective, it would be necessary to distribute the points of measurement (transducers) spatially and that was how the researchers did it. He commented that the distribution of transducers was well explained in the graphics provided in the draft final report.

Dr. Lehr stated that the researchers actually did <u>not</u> address measurement of slick thickness throughout the entire slick in the draft final report. Instead, the researchers measured surface oil thickness at various locations in the slick. Dr. Lehr commented that the ability to deploy an operationally practical tool during an oil spill incident that provided a trustworthy estimate of total surface oil volume would provide the “holy grail” of spill science.

Dr. Lehr commented that he was initially unsure, but BSEE’s written answers to the peer reviewer questions (see Section 7 (Appendix C)) clarified that the laboratory ISB experiments used multiple transducers. Dr. Garcia-Pineda pointed to Figure 5 (page 9) in the draft final report. Dr. Lehr stated that using sufficient transducers should allow acoustic measurements to estimate oil volume. Dr. Garcia-Pineda also pointed to Figure 37 in the draft final report (page 37) that showed the spatial distribution of transducers.

Dr. Lehr commented that thick oil collected in ISB boom systems that have an open end to the sea will have some small slope from front to back, but he thought that small slope would not be a big problem for measurement of slick thickness at specific locations in the slick with adequate placement of sufficient acoustic sensors to calculate the slope. Mr. Mabile explained that during ISB operations the oil within ISB boom systems being towed by boats will typically have a slope. Mr. Mabile mentioned that the draft final report (page 23) noted that the slick for larger burns would vary in thickness and the draft final report specifically stated that for larger burns “the spatial variations of the thickness will need to be measured to accurately determine the volume of oil.”

Dr. Weber added that the draft final report did not specifically discuss multiple transducers, and stated that he thought the transducers were at a fixed location for the laboratory ISB experiments. He stated that operational challenges will occur during ISB for placing transducers under the slick or installing on a remote operated vehicle (ROV) that will create technical challenges for measurement of varying slick thickness and also create sampling bias. Dr. Weber emphasized that significant temporal and spatial changes (e.g., thinning during burns) would occur in the slick during ISB operations that would create spatial sampling challenges.

Dr. Lehr stated that undulations in the slick will occur during ISB that will affect surface slope. Dr. Weber noted that boats will vary speed and anticipated that undulations will occur from varying boat speeds. Mr. Mabile explained that undulations will occur from varying boat speeds. Ms. Stone added that according to the USCG, boats should vary speed intentionally to create shimmy and cause undulations. Mr. Mabile disagreed and stated that only the USCG thinks that this shimmy occurs; from his experience, the fire will be against the ISB boom system. Mr. Mabile also stated that boats would sometimes move at different speeds in order to move the ISB boom system into a "J" shape if a portion of the boom failed. The purpose of moving an ISB boom system into a "J" shape is to increase the burn rate again. Dr. Lehr questioned whether wave lengths would become a significant issue.

Dr. Garcia-Pineda questioned whether slick thickness was important at all, because he expected that thickness would not affect ISB operations. Mr. Mabile commented that thickness created very little variance in the DWH burn rate calculations; instead, the area of the fire was more important. Dr. Weber commented that thickness may not be important and also stated that acoustic measurements of thickness may not improve the accuracy of overall oil volume estimates.

There was a general discussion among the reviewers that measurement of varying slick thickness throughout the entire slick was not explained adequately in the draft final report. Ms. Stone clarified that it was the vapors burning during the laboratory ISB experiments and not the oil burning.

Dr. Lehr asked whether using a submarine under the oil slick would work to measure a cross-section of slick thickness. The other reviewers generally believed that using submarines might work.

Charge Question 1.4: Does the report adequately address how the methodology for acoustic slick thickness measurements would be affected by waves and currents in open water conditions? Explain any issues or concerns that might affect the validity of this acoustical methodology in open water conditions.

Dr. Garcia-Pineda noted that the draft final report mentioned possibly operating an ROV under the surface, but he stated that ROV operation from a vessel would not be practical except under limited sea state conditions. He flies drones over the ocean all the time and confirmed that operating drones over the ocean is practical. Dr. Garcia-Pineda also stated that the acoustic system used in the study may have inaccuracies when turbulence was present, because turbulence (e.g., waves) would create difficulties aligning the transducer and the surface.

Dr. Lehr expressed concerns about the acoustic thickness measurement method when waves were present. He stated that interfering frequencies from wave actions on the surface might increase spatial return signal scatter and may even cause potential signal interference. Dr. Lehr noted that the draft final report on page 53 mentioned other studies where slick thickness measurements were successful for wave heights actually greater than the freeboard of many booms. Dr. Lehr stated that he had already reviewed those additional studies, which were listed in BSEE's written answers to the peer reviewer questions (see Section 7 (Appendix C)), and he will discuss this further in his final written response to this charge question.

Mr. Mabile stated that the draft final report had specifically mentioned that this study did not address waves from the sea surface, which will be an issue with ISB in open water conditions. Based on his experience, small choppy waves will always occur inside an ISB boom system, even if no waves exist on the sea surface. Small choppy waves within the ISB boom system occur because water is hitting the side of the boom. Mr. Mabile stated that his written response to this charge question had summarized and provided references for other studies with results that show the effects of currents on ISB burning rates are negligible.

Dr. Weber commented that the effect of waves and currents was not addressed in the draft final report. He stated that waves and currents could create emulsions, or gas bubbles, which could lead to increased volume reverberations for acoustic measurement. Dr. Weber anticipated that generally, in field operations, the process of taking measurements would not try to identify the same cycle of the reflected waves for different interfaces. He emphasized that identifying the same cycle of the reflected waves for different interfaces would only work under laboratory conditions. Dr. Weber stated that most echo sounders could do this.

Dr. Lehr asked Dr. Weber whether the signal from echo sounders will be quicker than the movement of waves. Dr. Weber drew a diagram indicating that there would be only two (2) fairly clean reflections—the air/oil interface and the oil/water interface, with the surfacing oil coming up through the water. Each interface would need to be identified and the ΔT (Delta T) between them measured. Dr. Weber emphasized that gas bubbles will make detecting the interfaces difficult because volume reverberations could make acoustic measurement unreliable. He further emphasized that if waves or currents occur that would also make the interfaces difficult to measure.

Mr. Mabile stated that any incongruence in oil, such as bubbles, would slow down the speed of sound. Dr. Weber explained that although the speed of sound in air is slower than the speed of sound in water, the sound speed depends on the relative quantity of gas and water.

Mr. Mabile asked Dr. Weber about the speed of sound in emulsions. Dr. Weber replied that although the draft final report had mentioned some experiments with emulsions, this information was not provided with the results of the laboratory ISB experiments.

Ms. Stone asked how noise would impact the speed of sound and also how that would impact thickness measurement. Dr. Weber replied that this study was about measuring the speed of sound while oil is burning, not about measuring slick thickness before deciding to use ISB. He explained that it would be necessary to detect both interfaces—air/oil and oil/water—and necessary to know the speed of sound in various oils.

Dr. Lehr asked Dr. Weber about the speed of sound in fresh water versus salt water. Dr. Weber replied that there is a difference in the speed of sound for fresh water versus salt water; however, there is a larger difference in the speed of sound for warm water versus cold water.

Charge Question 1.5: Are the assumptions of the oil thickness algorithm input clearly defined and appropriate (see Sections 2.2.4, 3.1.3, and 3.2.3)? If yes, explain why. If not, explain how those assumptions could be defined more clearly. Provide a rationale for your answer about the appropriateness of the assumptions of the oil thickness algorithm input.

Dr. Weber stated that the measurement algorithm itself was rather simple—the slick thickness was defined as the time difference of arrival for the two interface returns, multiplied by the sound speed and divided by two (2). Although he had a question about whether the harmonic mean was used, Dr.

Weber noted that BSEE's written answers to the peer reviewer charge questions (see Section 7 (Appendix C)) clarified that the study did not use the harmonic mean sound speed. Dr. Weber stated this problem could easily be fixed to improve the study.

Dr. Weber stated that the draft final report was very unclear about how the researchers obtained the temperature measurement and how the top of the slick was determined. Dr. Weber pointed to the graphs in Figure 14 of the draft final report (page 19), which he said showed that the thermocouples were out/up in the flames. Dr. Weber stated that the researchers made an assumption about where the top of the slick was, but emphasized that this critical assumption was not clearly described in the draft final report.

Dr. Weber noted that BSEE's written answers to the peer reviewer charge questions (see Section 7 (Appendix C)) referred to the Supplemental Information (see Section 1.4.1) provided for the peer review, but Dr. Weber stated that the assumption the researchers had made to identify the top of the slick was also not clearly described in the Supplemental Information (see Section 1.4.1). Mr. Mabile added that the purple line in the graph in the Supplemental Information (see Section 1.4.1) made no sense to him. Dr. Weber emphasized that the purple line in that graph should not be a straight line, and questioned the material that the researchers had provided in the Supplemental Information (see Section 1.4.1) for the peer review.

Dr. Garcia-Pineda stated that the assumptions of the oil thickness algorithm input were not clearly defined in the draft final report. He questioned how the algorithm dealt with geo-rectification and how the algorithm was designed to work with geometry constraints for camera viewing angles.

Dr. Lehr commented that the algorithm assumptions in the draft final report did not include the limitations or expected error ranges. Dr. Lehr expressed concerns that the draft final report provided no information about expected accuracy or measurement error. Dr. Lehr also commented that another unanswered question was the degree of horizontal spatial averaging done for the laboratory ISB experiments in this study.

Mr. Mabile noted that this was not his area of expertise, but he believed that oil thickness studies should be conducted on emulsified oil if BSEE's objective was to test acoustic measurement for use with ISB in offshore open water conditions.

Ms. Stone asked Dr. Weber if there was a flowing fuel fire, and if thermocouples were always in the slick, how would that situation affect acoustic measurement. Dr. Weber referred to the graph in the Supplemental Information (see Section 1.4.1) and explained that although the vertical axis was labeled as depth, it was actually not depth because depth will change. Dr. Weber drew a diagram to illustrate how it was only necessary to identify where the top of the slick was, and to measure the temperature gradient in order to get the harmonic speed of sound. Dr. Weber emphasized again that using harmonic mean sound speed would be the correct approach to acoustic measurement.

Charge Question 1.6: What are the strengths and weaknesses of the slick thickness determination methods? Provide a rationale for each identified strength or weakness.

Dr. Lehr stated that based on his review of the data (as illustrated in Figure 13, page 18), the method gets "noisier" or less reliable as the burn proceeds, and especially after significant burning begins. After boil over began in the laboratory ISB experiments, the thickness would become undefinable. He believed that boil over is probably not a problem for ISB in open water conditions. Dr. Lehr speculated that the slick thickness estimation methods used in this study could have errors of 50%. Dr. Lehr also commented that ASTM F-1788 data shows that the burn rates of oil are well established, and as such, he would not expect much error for the burn rates.

With respect to strengths, Mr. Mabile commented that having the capability of "real-time" thickness measurements during ISB operations would be great. Slick thickness measurement would be useful to help guide responders on where to use ISB.

Mr. Mabile described the weaknesses as: 1) thickness was measured only at the point in the slick where each of the transducer probes were positioned and did not represent the entire profile of the slick; 2) calibration of sound transducers is difficult with varying temperatures within the slick depth during ISB; 3) emulsification variability will be a real challenge for sound calibration, which was not included in this research; 4) the slick thickness profile within a towed ISB boom system varies and it would be necessary to lay out hundreds of acoustical probes and, more specifically, the draft final report does not mention sound beam spread and how much space to design between transducers; and 5) it would be cost prohibitive to have ROVs for each boat during ISB in open water conditions.

Dr. Weber commented that the strength of the method is the simplicity (measuring the travel time for echos) and that acoustic measurement is a proven technique that works in a variety of settings. He stated that the major weakness of the method was the need to measure the oil temperature gradient to convert speed of sound travel time measurements to distance. Dr. Weber stated another related weakness is the need to know the temperature-dependent sound speed of oil, which will probably be weathered oil during ISB in open water conditions. Dr. Weber commented that translating this method to actual ISB operations in offshore open water conditions would be difficult, even if the approach is valid for pan tests in the laboratory.

Dr. Garcia-Pineda stated that a strength was creating a tool to conduct more scientific tests under controlled settings to understand many other things, for example, possibly further laboratory ISB experiments of oil burning rates under different levels of emulsifications. Dr. Garcia-Pineda commented that the biggest weakness was the inability to transition this approach into an operating environment in offshore open water conditions. He thought the synchronization of unmanned aerial vehicles (UAVs) or drones, or ROVs, with the moving slick and the boats pulling a boom—all with acoustic measurement equipment on them—would be difficult. Dr. Garcia-Pineda also thought another major operational challenge would be synchronization of the photogrammetry needed with the deployment of the acoustic thickness system to collect measurements.

Dr. Lehr noted that Environment Canada (Fingas and Brown) had previously researched a similar technique using lasers, but then found that technique could not operationalized on aircraft. The motion from the moving aircraft interfered significantly with measurements using the lasers.

Dr. Weber emphasized that the acoustic method requires identifying the top of the slick, but he thought the researchers actually did not consider how to make that measurement. He added that the slick thickness measurement will not have a good ground truth.

Dr. Garcia-Pineda emphasized that the method needs an approach to evaluate the calibration of the slick thickness measurement. Dr. Weber commented that it would be much more powerful to have both a direct (calibrated) and indirect measurement of thickness.

Ms. Stone clarified that currently there was no good method to make direct measurement of *in-situ* oil slick thickness. Dr. Garcia-Pineda supported that statement.

Charge Question 2.1: Are the methods used to measure the surface area of the burning slick valid? If yes, explain why these methods are valid. If not, how could the validity of the area measurement methods be improved or more clearly described?

Dr. Garcia-Pineda commented that the researchers needed both a testing data set as well as a validation data set in order to evaluate the accuracy of the slick area measurement methods. He expressed concerns that the researchers did not demonstrate validity or how the researchers ensured that this study's experimental measurement methods actually worked or how the researchers ensured accurate measurements. Dr. Garcia-Pineda emphasized that to improve validity this study needed to demonstrate how the testing data from the laboratory ISB experiments were either different or consistent with calibration data. He stated that the researchers did not report which experiments failed to work. Dr. Garcia-Pineda emphasized that the draft final report for this study needed to include a comparison between the 30 burn tests in the laboratory ISB experiments, and provide more technical details to explain how the 30 burn tests were conducted (e.g., whether burning same amount of oil).

Ms. Stone stated that Figure 11 of the draft final report (page 15) illustrated a birds eye view of the slick area computation process. To provide an example of his concerns about the validity of the slick area measurement method, Dr. Garcia-Pineda stated that the researchers did not explain why the laboratory ISB experiments changed from six (6) cameras to three (3) cameras.

Dr. Weber asked Dr. Garcia-Pineda what criteria could be used to determine accuracy with respect to measuring the burning area for ISB in open water conditions. Dr. Garcia-Pineda explained that control points are necessary for geo-rectification of an image, and it appeared that the study used the corners of the tank. He further explained that such control points would also be necessary in the field, but the situation for ISB in open water conditions will be dynamic. Dr. Garcia-Pineda stated that for purposes of the study's laboratory ISB experiments, knowing the geometry of the tank was sufficient, but the researcher's experimental approach was far from being an automated algorithm.

Dr. Weber stated that the use of cameras from multiple angles to measure the surface area of the slick was not clearly described in the draft final report. He thought this was technically possible, but emphasized that there was almost no information in the draft final report to understand how the method provided the results. For example, he mentioned that the draft final report did not describe how the researchers detected fire, or absence of fire, in the images. Dr. Weber suggested that this study's final report should include more results on how the laboratory ISB experiments used a different number of cameras, and different camera angles, to determine the surface area of the burning slick.

Dr. Garcia-Pineda emphasized that it was important that the final report thoroughly describe the geometry of all the laboratory ISB experiments and that the final report also describe clearly what the researchers found was the ideal geometry based on the laboratory ISB experiments.

Dr. Lehr commented that during DWH surface mapping, some scaling was necessary to adjust the angles for cameras and that British Petroleum (BP) provided that information. Surface mapping requires adjustments for angles and distances, but he emphasized that none of that information for the study's laboratory ISB experiments was provided in the draft final report. Dr. Lehr noted that standard remote sensing uses solid reference points.

Dr. Garcia-Pineda added that there may be other approaches for a surface area algorithm that BSEE could consider, instead of the area measurement methods used in this study.

Mr. Mabile commented that during ISB in open water conditions, it would be possible to know the location of boom sections for an ISB boom system, which could be seen from the air and potentially be used as distance reference points. He stated that the laboratory ISB experiments in the study needed reliable control points to compare such control points to burn test results from the laboratory ISB experiments.

Mr. Mabile stated that he would have liked to see more information in the draft final report about how area averaging was conducted at the "sharp" contours of the area photos to derive the results from the laboratory ISB experiments. He questioned how much repeatability was included in the laboratory ISB experiments; although Dr. Garcia-Pineda had just mentioned 30 burn tests, Mr. Mabile thought the draft final report did not provide information about the repeatability of the laboratory ISB experiments that were conducted for this study.

With respect to the fire/water interface during ISB in open water conditions, Dr. Lehr and Dr. Garcia-Pineda emphasized that it will be necessary to address smoke obscuration.

Ms. Stone noted that BSEE would like to automate the slick area estimation to "near real-time" if possible.

Charge Question 2.2: Are the numbers of images, heights, and angles from around the fire adequate for accurate area computations using the photogrammetric methods reported? Explain how the approach chosen could affect the validity of the methodology and results.

Dr. Garcia-Pineda stated that the draft final report needed a sketch of the camera set-up, describing the range of heights, distances, and angles. He noted that BSEE's written answers to the peer reviewer questions (see Section 7 (Appendix C)), had provided some clarification, but not enough. Dr. Garcia-Pineda emphasized that this study's final report should provide all the results from the laboratory ISB experiments, such as describing what camera geometry (heights, distances, and angles) actually worked. Overall, based on the general information in the draft final report, Dr. Garcia-Pineda thought the geo-rectification technique made sense.

Dr. Lehr suggested that the approach for measuring the surface area of the burning slick could eventually be developed into a simplified formula. He questioned how it would be possible to separate the interfaces—air/oil and oil/water. For example, Dr. Lehr stated that the draft final report needed more technical details on how to correct for smoke obscuration in determining the fire area. Overall, he questioned how camera placement would work during ISB in open water conditions.

Mr. Mabile commented that the characteristics of the data gathering seemed adequate. He suggested that the approach heights and angles might be different for very large ISB operations. In his DWH experience, very large fires often had oxygen starvation in the center creating low burn efficiency, resulting in very dark black smoke. He also mentioned that during DWH, high winds could cause the smoke plume to lay down relative to the water surface, which could cause potential smoke obstructions for this method.

Dr. Weber noted that the draft final report demonstrated believable results with three images, and questioned whether that was sufficient for ISB in open water conditions. He stated that, from his perspective, he was not sure what “adequate” meant in this charge question.

Mr. Rock concluded Day-1 of the panel meeting at 5:30pm.

6.2.2 Day-2: December 12, 2017

Mr. Rock opened Day-2 of the panel meeting at 8:30am. He asked the reviewers if there was any further information to discuss about Charge Questions 2.1 and 2.2 from the previous day.

Ms. Stone asked Mr. Rock whether she could provide additional background information. Ms. Stone stated that the most important interface might be the interface of the fire with the oil, or the fire/burning-oil interface, especially at the back of the boom. Ms. Stone clarified that during the laboratory ISB experiments the cameras were pointing right at the base of the flame.

Dr. Weber commented that the reflection from the fire onto the water surface will create problems with this method. Mr. Mabile emphasized that the fire/burning-oil interface (as Ms. Stone had just identified as most important) is the <u>only</u> useful information to clearly identify the boundary area of the ISB. Dr. Garcia-Pineda commented that whenever something is not at the same level of the surface that will result in incorrect geo-rectification. He explained that a 3-D projection of this fire/burning-oil interface might be a better approach. Dr. Lehr clarified that Dr. Garcia-Pineda was recommending 3-D modeling for “slicing” the fire area as a better approach.

Charge Question 2.3: Does the report adequately address the methods to account for errors from obstructions and limited angles/heights/distances? Explain how the methods used to account for errors could affect the validity or scientific merit of the methodology and results.

Dr. Lehr stated that if the objective was actually to identify the fire/burning-oil interface (as Ms. Stone had just identified as most important) or to identify the interfaces used in the study—air/oil and oil/water—then he had noted during the previous discussions several important items, including the need to: 1) evaluate the surrounding pixels to make sure those pixels are at the interface(s); 2) separate smoke from fire, to address smoke obscuration; 3) address the problem of flame reflection on the water surface; and 4) address the problem of flame coming out of the smoke. Dr. Lehr stated that a 3-D approach might be more accurate to help identify what information should be discarded. In any case, he believed that the laboratory ISB experiment's pixel recognition algorithms must be further developed before such algorithms can be considered for use with ISB in open water conditions.

Dr. Lehr emphasized that the algorithm used for area measurement must have criteria to decide which pixels to use, but such criteria were not described in the draft final report for this study. He further emphasized that the approach must be able to define planes at the same scale.

Dr. Garcia-Pineda commented that the draft final report did not include enough details about how to account for errors in this method. He stated that additional levels of camera heights would add more information to account for errors. Dr. Garcia-Pineda recommended using at least two (2) more levels of camera heights, which would provide nine (9) layers. Dr. Garcia-Pineda explained that three (3) different layers at three (3) different heights would provide more robust information. He added that a drone will take images in a circle.

Ms. Stone asked Dr. Garcia-Pineda how a drone could be used to do that instantaneously. Dr. Garcia-Pineda responded that drones cannot be flown from multiple places during oil spill responses. He suggested that the same drone could be used with a one-minute time lapse to fly up and down to different levels and the images could be used to create a 3-D model of the ISB operations in offshore open water conditions. Ms. Stone noted that BSEE cannot fly drones because BSEE is a federal government agency. Ms. Doll noted that that the peer review should focus on evaluating the draft final report for this study and not discussing future research on other potential technologies.

Dr. Garcia-Pineda stated that a thermal sensor would need to be incorporated into this approach to account for flame reflection on the water surface.

Dr. Weber commented that the study had demonstrated a plausible conceptual model; however, more rigorous analysis was necessary to evaluate how to adequately account for different levels of smoke obstruction around the fire. He noted that the draft final report described smoke obscuration as problematic during the laboratory ISB experiments for both the visual and infrared cameras. He noted that ISB in open water conditions could have billowing smoke from winds and pointed to the third panel in Figure 1 of the draft final report (page 6). Dr. Weber emphasized that more rigor, more repeatability, and more analysis were needed to address methods to account for errors.

Mr. Mabile commented that the primary data of interest for ISB in open water conditions is the area of the fire and how it changes over time. In his experience with ISB, oil spill responders will start the fire, then the fire will go to a high burning rate, then deplete, then the fire will go out. Mr. Mabile stated that there is a temperature difference at the fire/burning-oil interface (as Ms. Stone had just identified as most important). He suggested that perhaps infrared cameras combined with other methods might help identify this fire/burning-oil interface.

Dr. Weber stated that identifying the boundary of the interfaces used in the study—air/oil and oil/water—was all that is needed, and stated that using infrared cameras is sufficient to identify these boundaries. Dr. Garcia-Pineda also stated that only infrared cameras are needed.

Dr. Weber asked Mr. Mabile if the smoke usually went off the back end of an ISB boom system. Mr. Mabile replied that occurs around 80% of the time during ISB in open water conditions and that the towing vessels can easily be maneuvered to avoid adverse smoke impacts on ISB personnel.

Dr. Garcia-Pineda commented that the fire/burning-oil interface (as Ms. Stone had just identified as most important) will be moving during ISB operations. He expressed concerns that BSEE was trying to solve a 3-D problem from an oblique perspective. He also expressed concerns that during ISB operations the location from which images are being taken will be moving, and that would cause error because there is a significant lag between the GPS signal and taking an image. Dr. Garcia-Pineda suggested that a 3-D model could be developed through flying UAVs, and questioned why BSEE would not consider obtaining 3-D images.

Dr. Lehr noted that Ms. Stone had suggested that eventually automation would provide instantaneous results using this proposed technology. Dr. Lehr expressed concerns that if this technology were to be automated, significant complexities in programming would be encountered because there will be too many variables for the wide range of often unpredictable situations that can occur during actual ISB operations in offshore open water conditions.

Charge Question 2.4: Are the assumptions of the area algorithm input with respect to burning area of the slick clearly defined and appropriate (see Sections 2.1.1, 3.1.1, and 3.2.1)? If yes, explain why. If not, explain how those assumptions could be defined more clearly. Provide a rationale for your answer about the appropriateness of the assumptions of the area algorithm input with respect to burning area of the slick.

Mr. Rock began the discussion of Charge Question 2.4 by noting that throughout the discussion of the charge questions about slick thickness as well as the previously discussed charge questions about slick area (2.1–2.3) the common thread seemed that the reviewers understood the concept, but the draft final report lacked sufficient technical detail to evaluate the methodology.

Ms. Stone provided additional background information to clarify that BSEE is encouraging the research report authors—Applied Research Associates (ARA)—to pursue a patent application, which she explained is allowed in BSEE's research program. Because it was important to protect ARA's patent application, much of the technical details about this study's methodology were intentionally excluded from the draft final report as well as the Supplemental Information (see Section 1.4.1) provided for the peer review. Ms. Stone also explained that BSEE's written answers to the peer reviewer questions (see Section 7 (Appendix C)) were also restricted to protect ARA's patent application. There was a general discussion among the peer reviewers about whether protecting ARA's patent application should be more important than providing sufficient technical details for a peer review to evaluate information quality for BSEE and to determine whether this study's methodology was good science.

Dr. Garcia-Pineda stated that it would be necessary to compare burn test results from the laboratory ISB experiments to calibration tests in order to evaluate the appropriateness of the assumptions of the area algorithm input with respect to burning area of the slick. Dr. Garcia-Pineda emphasized again that the draft final report needed information on calibration tests in order to evaluate the validity of the slick area measurement methods. He stated again that the laboratory ISB experiment results must be compared with equipment calibration results.

Dr. Lehr noted that in the laboratory ISB experiments the burn area was observed from multiple cameras, each with a different angle, but the actual number of cameras with a clear view of the reference points seemed as low as two (2) cameras. He explained that planar homography normally uses four (4) reference points to define the necessary common reference plane, but homography data was not included in the draft final report. Dr. Lehr questioned whether the laboratory ISB experiments used sufficient cameras to identify the known reference points.

Dr. Lehr emphasized that during actual ISB operations in offshore open water conditions, planar homography will become much more complicated because the fire area boundary will be constantly moving. Dr. Lehr stated that the draft final report noted on page 40 that the results of 30 burn tests could be used to empirically determine error and verify the limits of forming an accurate homography; however, no technical details or results for the 30 burn tests were provided so it was difficult to know if the errors were within an acceptable range.

Mr. Mabile commented that the researchers should have measured “x” for the surface area of the fire, “y” for the burn rate, and “z” for the time that the slick was burning, and a simple equation to obtain the product of those three (3) variables can be used to provide the result.

Dr. Garcia-Pineda pointed to Figure 43 in the draft final report (page 42) and explained that the fire reflection on the water surface in that image had occurred because of poorly chosen camera angles. He emphasized that it was important to choose the correct camera angles for accurate measurement with planar homography techniques. He also emphasized that it was important to constantly adjust the camera angles to reduce problems such as fire reflection on the water surface in the images. Because improved accuracy may depend on constantly adjusting camera angles, Dr. Garcia-Pineda commented that a moving camera was necessary for accurate results. He noted that using multiple camera angles can greatly reduce problems with reflection.

Dr. Garcia-Pineda pointed to Figure 36 in the draft final report (page 37) and commented that the angle of the cameras shown in this figure had such an oblique point-of-view that it would be difficult to obtain accurate results. He emphasized that it would be necessary to make the cameras much higher to obtain better angles. Ms. Stone noted that Figure 36 showed the cameras at a 45° angle.

Dr. Garcia-Pineda added that generally cameras should be placed starting from nadir (in aerial photography, nadir means the point on the ground vertically beneath the perspective center of the camera lens) and the camera angle should be changed until imaging problems such as reflections occurred, then select the optimum camera angle for the best images. He clarified that a 60° angle from the horizon (30° angle from nadir) would be the lowest he would recommend to collect the photographic images and it might range to a 45° angle from nadir (but not lower than that).

Charge Question 2.5: What are the strengths and weaknesses of the methods for the determination of the area(s) of the burning slick? Provide a rationale for each identified strength or weakness.

Mr. Mabile stated that the key strength was the promise of using automated equipment to more accurately and tirelessly perform fire area estimation. He stated that the weaknesses include limited flight times, more specifically, drone flight times are limited by battery life and aircraft flight times are limited by fuel capacity. Mr. Mabile suggested that BSEE consider testing this method for nighttime operations to determine the hurdles to operating in darkness. He mentioned that during DWH, ISB extended into the night a few times.

Mr. Mabile expressed concerns about the margin of error or accuracy, because that was not clearly defined in the draft final report. He pointed to Figure 11 of the draft final report (page 15), which showed that odd shapes of fire occurred during the laboratory ISB experiments. Mr. Mabile questioned what pixel resolution was used and how much estimation or "rounding off" was conducted for this study with respect to these odd fire shapes. Because in his experience, large burns during ISB operations will have many odd shapes and edges throughout those large burns, Mr. Mabile acknowledged that "normalization" for areas with odd fire shapes would be required.

Dr. Lehr asked all of the reviewers to look at page 42 of the draft final report and pointed out that the smoke area may be indistinguishable from, or obscuring of, the fire area, even in the infrared range. Dr. Lehr noted the draft final report stated that during the laboratory ISB experiments for this study the infrared camera could not distinguish between smoke and fire because both gave off heat. Dr. Lehr stated that the researcher's idea of using as few as two (2) cameras would not work. He mentioned that this study's final report should include more information to justify why the researchers had decided that two (2) cameras would work.

Dr. Garcia-Pineda stated that the draft final report did not explain the calibration of the infrared cameras. He emphasized that a more accurate approach would require demonstrating a calibration point, and using that to normalize any offset or error from the infrared cameras.

Dr. Weber commented that the main strength of the method used in this study to determine the area of the burning slick was the simplicity of measurement and that the method was not conceptually difficult. He mentioned that the technology of using drones at sea to collect camera images for measurements is routinely used and probably could be applied to ISB in open water conditions. Dr. Weber stated that the main weakness was obscuration of the burning area or flame by smoke, which could be blowing and billowing smoke as he noted was shown in Figure 1 of the draft final report (page 6). He expressed concerns that blowing and billowing smoke could cause large biases in estimating the area of the burning slick.

Dr. Weber asked whether it would be correct to assume that the entire area inside the burning area of a slick was actually flame for ISB in open water conditions. Dr. Lehr explained that the center of the burning area for a slick may be oxygen starved, and that oxygen-starved part of the burning area may burn less efficiently during ISB operations. Dr. Weber asked what would happen if the center of the burning area of the slick "coked out." Mr. Mabile presented a video of ISB during DWH that illustrated large burns.

Introduction to Charge Questions 3.1–3.5

Ms. Doll referred to the amended Charge Questions 3.1–3.5, which Ms. Doll had distributed earlier during Day-2 of the panel meeting. Based on discussions with the BSEE COR (Ms. Stone) for this task order, the EnDyna Peer Review Lead added the text "To demonstrate the technology proof of concept" to the beginning of Charge Questions 3.1–3.5, as shown below (using red font and underline).

Ms. Doll explained that the purpose of adding this additional text was to focus the peer reviewer's responses more effectively on how well the draft final report for this study demonstrated the technology proof of concept for ISB in open water conditions. Because BSEE had specifically requested expertise with ISB in open water conditions, these amended charge questions were intended to help evaluate the technology proof of concept based on this specific area of expertise requested by BSEE for this peer review.

Ms. Doll noted that that the peer review should focus on evaluating the draft final report for this study and not planning ahead for future research that BSEE may conduct at higher TRLs. The BSEE scope of the peer review is focused on the methodology used in the draft final report to determine burn volumes, burn rate, and burn efficiency.

- **Charge Question 3.1:** To demonstrate the technology proof of concept—Does the report adequately address the methodology to accurately calculate the volume of the entire slick given the differences in thicknesses throughout the entire slick being burned? Explain how this affects the validity or scientific merit of the methodology and results.

- **Charge Question 3.2:** To demonstrate the technology proof of concept—Does the report describe with reasonable accuracy how burn volumes, burn rates, and burn efficiencies are computed? If yes, explain why these computations are described with reasonable accuracy. If not, how could the report describe these computations more clearly or with improved accuracy?

- **Charge Question 3.3:** To demonstrate the technology proof of concept—Are the limitations and uncertainties clearly identified and adequately characterized for the determination of burn volumes, burn rates, and burn efficiencies? If yes, explain why. If not, how could the limitations and uncertainties for the determination of burn volumes, burn rates, and burn efficiencies be described more clearly or characterized with improved accuracy?

- **Charge Question 3.4:** To demonstrate the technology proof of concept—What are the strengths or weaknesses of the methods used for the computations? Provide a rationale for each identified strength or weakness.

- **Charge Question 3.5:** To demonstrate the technology proof of concept—Are there any other conclusions that could be drawn that are not adequately addressed in the report? Are there any other issues or concerns with the validity of the methodology or results that were not included in the previous charge questions?

Ms. Stone emphasized again that this was a **proof of concept** study. The study's objective was to develop and test methods to directly measure the volume of oil burned and the burn rate in real time—eventually for use during ISB in open water conditions (particularly in the Arctic, where ISB may be the only oil spill response countermeasure that is feasible)—by integrating the direct thickness measurements using acoustic methods and surface area measurements derived from visible and infrared images.

Mr. Rock asked if any of the peer reviewers had any questions about these amended charge questions, and there were no questions.

Charge Question 3.1: To demonstrate the technology proof of concept—Does the report adequately address the methodology to accurately calculate the volume of the entire slick given the differences in thicknesses throughout the entire slick being burned? Explain how this affects the validity or scientific merit of the methodology and results.

Dr. Garcia-Pineda stated that the draft final report did not advance or demonstrate the technology proof of concept. He stated that conducting 30 burns tests was good, but expressed concerns that no technical details or results were provided about the 30 burn tests mentioned in the draft final report. Dr. Garcia-Pineda thought, at best, this study might take the technology to TRL-3, but he would like to see technical details and results for each of the 30 burn tests to confirm. He would also like to see more technical details on whether calibration of the transducers was done through measurements of thicknesses of known oil volumes.

Dr. Lehr pointed to page 53 of the draft final report, which stated that this research project did not attempt to measure spatial variations of thickness—because that was actually not attempted, Dr. Lehr stated it was not possible to adequately address a methodology for estimating spatial thickness variation from the research conducted for this report.

Dr. Lehr stated that the methodology for estimating thickness itself was probably valid; however, he emphasized that it would be necessary to review the technical details and results from the 30 burn tests to confirm. Dr. Lehr stated that the draft final report needed to thoroughly describe how the data was integrated from different transducers under the slick. He also stated that this study needed a secondary method for validation.

Mr. Mabile stated that the draft final report did not adequately address the methodology to accurately calculate the volume of the entire slick given the differences in thicknesses throughout the entire slick being burned. He mentioned that the validity could be improved by using more than one method to verify the volume of oil being burned, and suggested considering the use of pressure transducers. He also stated that this study's final report should indicate the percent accuracy of any measurement devices and any validation methods used. Specifically, he mentioned that the draft final report did not indicate how many transducers were required to cover a sufficient area of the entire slick to ensure accurate thickness measurements.

Ms. Doll asked Mr. Mabile for clarification about whether thickness is important for planning ISB in open water conditions. Mr. Mabile replied that it is probably not possible to measure slick thickness to evaluate the burn rate, because during ISB the slick thickness will vary rapidly within the ISB boom system. Mr. Mabile stated that using a well-established oil burn rate is sufficient, which was the approach used in DWH ISB operations. Mr. Mabile stated that the biggest variable in calculating oil volume is the slick area. He added that among the three variables (area, time, burn rate), the burn rate is what varies the least. Mr. Mabile commented that monitoring and measuring the burn area is significantly more difficult resulting in a larger margin of error as compared to errors associated with using an estimated burn rate.

Dr. Lehr asked Mr. Mabile about the effect of water content for emulsions on oil removal with ISB. Mr. Mabile stated that water-in-oil emulsions will lower the burn rate, but the well-established emulsified oil burn rates are applied in developing a burn rate "range."

Dr. Lehr asked Mr. Mabile how that would work for filling out the oil budget for decision-makers during oil spill responses, because decision-makers need an oil removal rate. Mr. Mabile stated that the hot fires during ISB for DWH caused a de-emulsification process, especially as the ISB boom system pulled the oil slick. Dr. Weber mentioned that he did not realize the boom would be scooping up more oil and thus more oil would be coming into an ISB boom system while some oil was burning. Mr. Mabile stated that it was not practical to calculate an instantaneous burn rate; instead, Mr. Mabile recommended thinking about the ISB operation as an "oil removal rate," analyzed by the product of the best estimated fire area calculation, multiplied by burn duration, and then multiplied by a burn rate range already established for different crude oils.

Dr. Weber asked for clarification about whether it was necessary to calculate how much additional oil was coming into the ISB boom system during ISB operations. Dr. Garcia-Pineda asked whether anyone had looked at quantifying the volume of smoke as a potential indicator of oil removal. Dr. Lehr replied that the National Institute of Standards and Technology (NIST) had calculated the percentage of burned oil that became smoke. Dr. Garcia-Pineda commented that it would not be possible to answer the question of how much additional oil is coming into the ISB boom system during ISB operations.

Mr. Mabile emphasized again that among the three variables (area, time, burn rate), the area and time are more important than the burn rate. Dr. Garcia-Pineda asked again whether evaluating the volume of smoke could help estimate oil removal from burning.

Dr. Weber noted that as a variable, area would be important for measuring slick thickness, but he stated that measuring slick area would only work in a static environment. Dr. Garcia-Pineda stated that accurate measurement of slick area would only work in static environment.

Ms. Stone noted that only around the first two inches of water in the ocean will absorb heat from ISB, and that she believed ROVs could operate under ISB for measuring slick area. In addition, Ms. Stone drew a diagram to illustrate the idea of using a "gate area," which would be a static area outside the ISB boom system for collecting oil.

Dr. Lehr stated that the oil budget developed for decision-makers uses a standard burn regression rate and estimates the oil budget by mass.

Dr. Weber summarized the previous discussion by noting that there were many issues with measuring slick thickness. Dr. Garcia-Pineda asked whether slick thickness should be studied for use in better evaluating the oil burn rate. Mr. Mabile stated that numerous research studies have already been conducted on oil burn rates, and those previous studies have provided already well-established oil burn rates.

Dr. Weber commented that measuring the thickness of oil pooled under ice might be a good way to use this method. Dr. Weber asked Ms. Stone if estimating the spatial variability along the oil slick was what this method was all about, and Ms. Stone replied yes.

Dr. Weber noted that there was a nuance to this approach that he did not understand, specifically whether sensors could be moved around to estimate different thicknesses and if that was possible, then it should be done; otherwise he thought the researchers did not adequately address the methodology to accurately calculate the volume of the entire slick given the differences in thicknesses throughout the entire slick being burned. Dr. Weber emphasized that it would be necessary to know the temperature profile from the top of the slick to the bottom of the slick, and further emphasized that it would be difficult to identify the top of the slick.

Dr. Weber emphasized that to advance the technology proof of concept for ISB in open water conditions, this temperature profile of the slick must be measured over the same spatial and temporal scales as the acoustic measurement itself. Dr. Weber explained that inaccurate estimation of this temperature profile or obstructions from billowing smoke could cause bias in calculating total volume of oil removed. He also emphasized that the size of this bias/uncertainty must be assessed in order to evaluate the validity or scientific merit of the study's methodology and results.

Dr. Weber pointed to Figure 13 (page 18), Figure 14 (page 19), and Figure 15 (page 20) as well as the figure in the Supplemental Information (see Section 1.4.1) provided for the peer review. Dr. Weber stated that the researchers did not interpret any of these results properly. He emphasized again that it was essential to have the temperature profile from the top of the slick to the bottom of the slick, and essential to identify the top of the slick, in order to advance the technology proof of concept for this study's method and accurately calculate the volume of the entire slick given the differences in thicknesses throughout the entire slick being burned.

Dr. Garcia-Pineda asked whether measuring the slick thickness along the boom before ISB might work, but no reviewers responded.

Charge Question 3.2: To demonstrate the technology proof of concept—Does the report describe with reasonable accuracy how burn volumes, burn rates, and burn efficiencies are computed? If yes, explain why these computations are described with reasonable accuracy. If not, how could the report describe these computations more clearly or with improved accuracy?

Dr. Weber began by noting that BSEE's written answers to the peer reviewer questions (see Section 7 (Appendix C)) had stated the researchers were making 50-second averages, and he explained that 50-second averages are not instantaneous measurements. Dr. Weber had questions about benchmarking, which he stated would require knowledge of the oil density as a function of temperature, including its depth variation. He expressed concerns that such benchmarking would require developing an integral or average, but this was not described in the draft final report.

Dr. Weber explained that estimating harmonic mean sound speed is required for conversion of travel time to sound speed, but BSEE's written answers to the peer reviewer questions (see Section 7 (Appendix C)) stated that this study did not use harmonic mean sound speed. He emphasized again that estimates of sound speed require estimates of the temperature profile of the slick. Dr. Weber noted again that the draft final report did not explain how the top of the slick was identified from the thermocouple data. He also noted again that although it appeared some smoothing or filtering of thickness data was conducted, this was not explained in the draft final report.

Mr. Mabile commented that the purpose of the study was to automate oil volume calculations. He stated that overall the draft final report did not clearly describe this study's computations and results. He noted that Figure 23 in the draft final report (page 26) did not label the Y-axis. Mr. Mabile pointed to Table 1 in the draft final report (page 27) and stated that this burn rate data seemed to match previous research studies. Mr. Mabile emphasized that the draft final report needed to provide the formula to explain more clearly how oil volume was calculated. He also stated the draft final report needed to provide the data on what burn rate was used in the calculations, and noted that Table 1 listed three (3) burn rates.[6]

Mr. Mabile asked Dr. Lehr whether NOAA would need oil volume for calculating the oil budget, and Dr. Lehr said yes. There was a general discussion among the reviewers about whether oil volume was reported in the study, and after looking through the draft final report, some volume data was found in Table 2 in the draft final report (page 28). After looking more closely at Table 2, Mr. Mabile commented that the units (cm^2) were incorrect and all reviewers then commented that those units should be cm^3 instead.

Dr. Lehr emphasized again that because the draft final report did not include error bars for any measurements, it was not possible to evaluate the accuracy of results. Dr. Lehr questioned whether the study measured burn rate through regression or some simple calculation. He emphasized that crude oil density changes with temperature. Dr. Lehr thought that using a standard density is probably sufficient if oil is not at extreme temperatures.

Dr. Lehr pointed to Table 1 in the draft final report (page 27) and commented that this table seemed to make sense, but he stated that the graph in Figure 25 below it showed something different. Dr. Lehr believed that Table 1 and Figure 25 in the draft final report (page 27) were counterintuitive.[7] He emphasized that Figure 25 was not explained clearly in the draft final report.

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[6] During discussions at the peer review panel meeting, Table 1 in the draft final report (page 27) may have been misleading for the peer reviewers. It was not clear from the draft final report that Table 1 was actually citing one of this study's references (see page 54 of the draft final report), specifically reference #2 or Buist, et al (2003). After the panel meeting, the EnDyna Peer Review Lead identified this issue, and contacted the reviewers to check whether the reviewers interpreted Table 1 as data cited from the Buist, et al (2003) report (versus interpreting Table 1 as burn rate data from this study's laboratory ISB experiments). One reviewer revised final written comments and another reviewer had avoided addressing Table 1 in final written comments; however, the final peer review panel meeting minutes were not revised.
[7] During discussions at the peer review panel meeting, Table 1 in the draft final report (page 27) may have been misleading for the peer reviewers. The previous footnote provides a detailed explanation.

Dr. Garcia-Pineda stated that the fundamental problem with the slick thickness part of the draft final report is that results were provided for only one experiment. For good science, Dr. Garcia-Pineda emphasized that it was critical to evaluate the repeatability of results from the 30 burn tests. He argued that in particular it was necessary to provide all the burn test results to evaluate data outliers, which may indicate the variables that are most important for further evaluation.

Dr. Garcia-Pineda stated that error bars should be provided for all the measurements. Dr. Lehr commented again that error bars should be provided for all measurements. Dr. Lehr elaborated that this study's final report should provide detailed results with error bars for all the laboratory ISB experiments conducted in this study, and also that all the aggregated results reported from the laboratory ISB experiments should have error bars.

Charge Question 3.3: To demonstrate the technology proof of concept—Are the limitations and uncertainties clearly identified and adequately characterized for the determination of burn volumes, burn rates, and burn efficiencies? If yes, explain why. If not, how could the limitations and uncertainties for the determination of burn volumes, burn rates, and burn efficiencies be described more clearly or characterized with improved accuracy?

Dr. Lehr commented that the limitations and uncertainties for the determination of burn volumes, burn rates, and burn efficiencies were not clearly described or characterized in the draft final report. He suggested that the researchers may have this data and, if so, this data should be included in this study's final report. Dr. Lehr stated again that the graphs in the draft final report did not provide error bars. He also stated that no data or calculations were provided in the draft final report for the 30 burn tests in the laboratory ISB experiments; however, he noted that the draft final report stated that those 30 burn tests could be used to empirically determine error. Dr. Lehr mentioned that a chart providing information about burn rate calculation accuracy versus peak wave height would be useful. Dr. Lehr also mentioned that it would be useful to have a graph of area estimate uncertainty as a function of average view angle.

Mr. Mabile stated that not clearly identifying the oil volume calculations was a very important limitation of the draft final report.

Dr. Weber stated that some limitations were described in the draft final report, including the problem of smoke obscuring the burning area. Although the smoke problem was discussed, Dr. Weber emphasized that the draft final report did not discuss the very important issue of potential uncertainty or bias from smoke obscuration. Dr. Weber stated that another important limitation was that the draft final report did not discuss the requirement for slick temperature profiles, and did not discuss the need to know the sound speed of oil over a very wide temperature range. Overall, Dr. Weber was not convinced that this method would work if those limitations were not addressed.

Dr. Weber commented that the draft final report has many significant flaws. For example, the draft final report did not include any assessment of uncertainty, and did not include any equations. Overall, Dr. Weber believed that no uncertainty analysis was conducted for this study based on the information in the draft final report. He also commented that lack of analysis of repeatability for the laboratory ISB experiments was a limitation.

Dr. Garcia-Pineda reacted to the explanation provided earlier by Ms. Stone that protection of ASA's patent application was the reason that so much critical information was missing from the draft final report. Dr. Garcia-Pineda emphasized that a patent application was not an acceptable reason to exclude critical information necessary to evaluate whether this study was good science. Dr. Garcia-Pineda expressed significant concerns that because this study was conducted with BSEE funding, the results should be available for peer review and for the study's final publication without restrictions.

Mr. Mabile stated that research on emulsions would be necessary to measure the speed of sound and measure slick thickness with varied states of emulsified oil to develop a method that was useful for ISB in open water conditions. Mr. Mabile commented that such research on emulsions would be critical to bring this method up to BSEE's TRL-6.

Dr. Weber commented that if there was a fundamental need to demonstrate the technology proof of concept with emulsified oil, then he believed that the TRL-3 level for this study (as described by Ms. Stone in her Day-1 background presentation) should be lowered. Ms. Stone explained that this method was intended primarily for use in the Arctic, where emulsified oil could occur less frequently during oil spills.

Dr. Lehr stated that it would be necessary to review all the formulas for the calculations as well as detailed data from experiments that actually covered the full range of parameters in order to evaluate how to move the technology proof of concept up the TRL levels.

Mr. Mabile suggested that perhaps the method should not focus that much on slick thickness. He commented that ISB would probably be the primary oil response countermeasure in Arctic conditions. He noted that BSEE's TRL-5 includes testing a prototype of the technology in "relevant environments."

Ms. Stone noted that BSEE may need to consider the uncertainty related to the view angles of cameras used in this method.

Dr. Lehr continued his comment by emphasizing again that it will be necessary to test these methods and algorithms on different parameters to evaluate which parameters are more important.

Charge Question 3.4: To demonstrate the technology proof of concept—What are the strengths or weaknesses of the methods used for the computations? Provide a rationale for each identified strength or weakness.

Dr. Garcia-Pineda commented that although it seemed that the simple arithmetic computations made sense as presented, the draft final report lacked sufficient detail to understand the methods used for the computations. He emphasized that the main weakness of the draft final report was the lack of data presented.

Dr. Weber stated that the draft final report needed more information on the methods used to "massage" the data. He reiterated the important limitations of the draft final report that he had already mentioned, including no discussion of the requirement for slick temperature profiles or knowledge of the sound speed of oil over a very wide temperature range for slick thickness measurement, and no discussion of potential uncertainty or bias from smoke obscuration for slick area measurement.

Mr. Mabile stated that the weakness of the draft final report was the lack of information on the computations, such as the data normalizing process. He suggested it was important that the draft final report include the formulas for how the oil volume was calculated. Mr. Mabile mentioned that interpreting the graphs in the draft final report was difficult because the draft final report did not provide enough information on the computations.

Dr. Lehr commented that conceptually it was easy to understand what the simple calculations were intended to do for this study. He stated that it was difficult to evaluate strengths or weaknesses for the more complex calculations that were not explained in the draft final report, such as signal-to-noise ratio from the acoustic measurements and view correction uncertainty using planar homography.

Ms. Doll asked Ms. Stone about whether the draft final report addressed ISB efficiency, which was included in the title of the draft final report. Ms. Doll noted that measurement of ISB efficiency did not seem to be addressed in the draft final report and that there had been little discussion about ISB efficiency during the peer review panel meeting. Ms. Stone explained that the researchers had collected residue from burn tests after the laboratory ISB experiments, but did not include that information in the draft final report.

Dr. Lehr stated that volume is what NOAA uses for the oil budget, and commented that ISB burn efficiency would be useful for the oil budget. Mr. Mabile explained that residue would be left in the ISB boom system and after collecting more oil, the residue would be burned again with the additional oil. Dr. Weber commented that the study did not address the speed of sound for residue. Ms. Stone explained that some residue was measured at CRREL in the final laboratory ISB experiments, but that was not included in the draft final report. For clarification, Dr. Weber pointed to page 49 of the draft final report, where residue collection and ISB efficiency were mentioned briefly.

Mr. Mabile mentioned that operationally a belt skimmer or vacuum would be used to pick up residue from ISB, and some residue might sink. He noted that residue could also be manually collected using nets. Mr. Mabile explained that research has demonstrated that residue from ISB is almost non-toxic.

Charge Question 3.5: To demonstrate the technology proof of concept—Are there any other conclusions that could be drawn that are not adequately addressed in the report? Are there any other issues or concerns with the validity of the methodology or results that were not included in the previous charge questions?

Mr. Mabile commented that the researchers could have drawn additional conclusions by comparing the burn rates from this study's laboratory ISB experiments with other laboratory ISB studies/tests from previous published research. For example, Mr. Mabile noted that the 2mm thickness threshold for ISB correlated well with previous experiments and published reports.

Mr. Mabile pointed to the end of the third paragraph of the Executive Summary of the draft final report (page 4; similar statements were repeated on pages 26 and 54) and stated that it was not true that this study set a precedent of measuring ISB burn rates dynamically. Because this was incorrect, Mr. Mabile questioned whether the researchers had conducted a literature review. Mr. Mabile commented there were some other misleading statements in the draft final report and emphasized that many other laboratory ISB studies have already been conducted on fresh ANS crude oil.

Mr. Mabile expressed concerns that the draft final report had “brushed over” volume calculations. Overall, Mr. Mabile had concluded from the panel discussions that he was not enthusiastic about the value of measuring slick thickness for planning ISB operations.

Dr. Weber commented that deriving conclusions from laboratory ISB experiments does not mean that a methodology can later be operationalized in the field.

Dr. Lehr expressed appreciation that the researchers made a “pretty good effort” for this study. To make an overall assessment, Dr. Lehr had asked himself whether there was a case for significant and consequential improvement over present methods, but stated that he had concluded probably not. Dr. Lehr believed that this method could probably not be automated under the dynamic conditions encountered during actual ISB operations in offshore open water conditions. He suggested that this method might be useful as a secondary check on the professional judgment of ISB experts. Dr. Lehr emphasized that the researchers would need to back up the method with adequate data before this method could be considered good science by oil spill science experts.

Dr. Garcia-Pineda pointed to the Summary and Conclusions of the draft final report (page 54) where the researchers stated that they applied the study’s measurement methods to various types of crude oils in the laboratory, and expressed concerns that analysis of different oils was not discussed in the draft final report. Overall, Dr. Garcia-Pineda believed that this technology proof of concept did not advance through BSEE’s TRLs as the researchers had described in the last paragraph of the Summary and Conclusions of the draft final report (page 54).

Dr. Garcia-Pineda mentioned that the limitations found with the slick area measurement methods in this study would lead him to suggest that 3-D methods might work better.

Dr. Garcia-Pineda noted that BSEE’s written answers to the peer reviewer questions (see Section 7 (Appendix C)) had not provided a helpful answer to his question about whether thermal imaging had any value for planar rectification. He emphasized again that it was important to use control or reference points to calibrate temperature measurements. Dr. Garcia-Pineda explained that he would prefer that the draft final report had provided the actual temperature data instead of pixel values as colors. He suggested including some discussion in this study’s final report about the limitations of operating UAVs during oil spill responses. Overall, Dr. Garcia-Pineda had concluded from the panel discussions that 3-D modeling was the best approach, especially if using drones or UAVs with a camera on the bottom or if relying on pilots with aircraft.

Ms. Stone asked Dr. Garcia-Pineda if mapping accuracy would depend on the elevation of drones from the water surface. Dr. Garcia-Pineda replied that Real Time Kinematic (RTK) positioning capabilities have been available for about 20 years to enhance the precision of mapping accuracy.

Dr. Weber pointed to the Summary and Conclusions of the draft final report (page 54) where the researchers mentioned the application of herders, and questioned why no data or conclusions were provided for herder applications. Ms. Stone stated that because herders were out-of-scope for this study, she had told the researchers to remove herder applications from the draft final report.

Mr. Rock announced a break, and stated that additional discussion of Charge Question 3.5 would proceed after the break.

Dr. Garcia-Pineda commented that best professional judgment would be necessary for slick area measurement if an oil spill happened today and suggested that drones should be considered further. He explained that dynamic GPS logging would be recorded for each image photographed by a drone. He also explained that a camera gimbal on a drone will hold the camera stable and record the camera angle for each image. Dr. Garcia-Pineda added that knowledge of the geometry of the camera lenses was also important.

Dr. Weber expressed concerns that there was no objective way to estimate the accuracy from using drones for this method. Dr. Garcia-Pineda clarified that drones are not the most relevant consideration for advancing the technology proof of concept through BSEE's TRLs. He believed that currently this study was at TRL-2.5, and to advance the TRL the researchers need to provide BSEE proof of repeatability for the laboratory ISB experiments as well as a validation test for the study's results.

Mr. Mabile recommended testing/calibrating acoustic thickness measurements through varying emulsions (from 0-50% emulsified oil). He also recommended measuring slick thickness using the "gate area" concept (an area at the leading edge of a towed ISB boom system) that Ms. Stone had described earlier.

Mr. Mabile drew a diagram and asked the other reviewers whether it would be feasible to consider placing a net under the ISB boom system with transducers on the net. Dr. Lehr asked whether it would be feasible to put a line of transducers in front of the boom instead. There was some general discussion among the reviewers indicating these approaches would probably not be feasible.

Mr. Mabile stated that 2000°F is the temperature from large ISBs, which boom manufacturers measured with thermocouples on test ISB boom systems. He wrote the following on the white board: Oil Volume = Area x Time x Rate. Mr. Mabile explained that Area is the variable in this equation with the most variation, and he recommended focusing on automated and consistent Area calculations to advance the TRL.

Given that thermocouples have been used on test ISB boom systems, Dr. Weber asked whether transducers could be placed on the skirts of booms. Mr. Mabile explained that during DWH a lot of oil was burned outside the ISB boom systems and estimates will be needed for that oil removed.

Dr. Garcia-Pineda mentioned that for mapping accuracy, it will be important to have as many points of reference as possible. Dr. Weber added that knowing the camera angle and field of view are also important. Dr. Garcia-Pineda explained that certifying the accuracy of mapping from drones, which he is qualified for, requires a certain density of reference points. Mr. Mabile provided some examples of reference points that could be used with ISB operations. Dr. Garcia-Pineda further explained that offsets will always occur and distortions must be accounted for.

Dr. Lehr stated that it would be necessary to use infrared cameras, and to develop software that is stable enough and reliable to use. He mentioned that ideally updated data would be needed for each Incident Action Plan.

Mr. Rock asked Ms. Stone whether she wanted any final clarifications from the peer reviewer's discussions about the charge questions during the panel meeting.

Ms. Stone asked Dr. Weber how easily the harmonic mean sound speed could be included in the current study. Dr. Weber replied that it should be fairly straightforward to include harmonic mean sound speed. Ms. Doll noted again that that the peer review should focus on evaluating the draft final report for this study and not planning ahead for future research.

Ms. Stone asked Dr. Garcia-Pineda to explain the reason for his earlier comment that the draft final report needed a sketch of the camera set-up, describing the range of heights, distances, and angles. Dr. Garcia-Pineda explained that knowledge of the entire geometry of the camera set-up was necessary to achieve repeatability for the laboratory ISB experiments.

Ms. Stone asked Dr. Weber to explain further about the bulk modulus and why the speed of sound is not related to the viscosity of the oil. Dr. Weber briefly reviewed, and stated he would provide more details in his final written peer review comments.

Ms. Doll reminded the peer reviewers about the Non-Disclosure Agreement (NDA) they had signed prior to starting the peer review, and that the discussion at the panel meeting was covered by their signed NDAs. All the discussions throughout the panel meeting were confidential for the participants only, and for the reviewers to consider in developing their final written peer review comments. These peer reviewer confidentiality requirements were specified in each reviewer's Peer Review Materials Package.

Ms. Doll also reminded the peer reviewers that they should use the amended Charge Questions 3.1–3.5, which were distributed and discussed during Day-2 of the panel meeting, when developing their final written peer review comments. Because BSEE had specifically requested expertise with ISB in open water conditions, these amended charge questions were intended to help evaluate the technology proof of concept based on this specific area of expertise requested by BSEE for this peer review. Ms. Doll explained again that the purpose of adding this additional text was to focus the peer reviewer's responses more effectively on how well the draft final report for this study demonstrated the technology proof of concept for ISB in open water conditions.

Ms. Doll emphasized that although the amended charge questions address "To demonstrate the technology proof of concept," it was important for the peer reviewers to understand that they were not expected to provide technical details on how the BSEE COR should write an SOW for future research projects. Ms. Doll reminded the peer reviewers that she had interjected several times during discussions in the afternoon of Day-2 as a reminder that the peer review should focus on evaluating the draft final report for this study and not planning ahead for future research on other technologies.

Ms. Doll explained that the peer reviewers should provide individual feedback on the draft final report in developing their final written peer review comments. This individual feedback should be based on their areas of expertise. She reminded the peer reviewers that the BSEE scope of the peer review is focused on the methodology used in the draft final report to determine burn volumes, burn rate, and burn efficiency.

Mr. Rock concluded Day-2 of the panel meeting at 4:30pm.

6.3 Agenda

The agenda for the panel meeting is presented below.

Monday, December 11, 2017

8:30am	**Arrive at EnDyna office**
8:45-9:00am	**Welcome and Introductions; Review of Agenda/Process for 2-day Panel Meeting** Smita Siddhanti, EnDyna
9:00-9:20am	**Background on BSEE Study:** Karen Stone, Oil Spill Response Engineer, BSEE
9:20-9:30am	***In-Situ* Burning Video (DWH ISB Team operations):** Mr. Neré Mabile
9:30-10:00am	**General Impressions:** Provide overall impressions addressing the accuracy of information presented, clarity of presentation, and soundness of conclusions. ***(each reviewer will present a high-level summary using around 5 minutes)***
10:00-10:15am	BREAK
1. Quantification of Slick Thickness:	
10:15-11:00am (45 mins)	**Charge Question 1.1:** Are the methods used to measure the oil slick thickness throughout the entire length of the *in-situ* burn tests valid? If yes, explain why these methods are valid. If not, how could the validity of the oil slick thickness measurement methods be improved or more clearly described?
11:00-11:45am (45 mins)	**Charge Question 1.2:** Is the method to quantify the speed of sound in oil during *in-situ* burning operations valid? If yes, explain why the method is valid. If not, how could the validity of the speed of sound in oil quantification method be improved or more clearly described?
11:45-1:00pm	LUNCH (on your own)
1:00-1:45pm (45 mins)	**Charge Question 1.3:** Does the report adequately address the measurement of varying slick thickness throughout the entire slick? If yes, explain why this measurement is adequately addressed. If not, how could these measurements be improved or more clearly described?
1:45-2:30pm (45 mins)	**Charge Question 1.4:** Does the report adequately address how the methodology for acoustic slick thickness measurements would be affected by waves and currents in open water conditions? Explain any issues or concerns that might affect the validity of this acoustical methodology in open water conditions.
2:30-3:15pm (45 mins)	**Charge Question 1.5:** Are the assumptions of the oil thickness algorithm input clearly defined and appropriate (see Sections 2.2.4, 3.1.3, and 3.2.3)? If yes, explain why. If not, explain how those assumptions could be defined more clearly. Provide a rationale for your answer about the appropriateness of the assumptions of the oil thickness algorithm input.
3:15-3:30pm	BREAK

3:30-4:15pm (45 mins)	**Charge Question 1.6:** What are the strengths and weaknesses of the slick thickness determination methods? Provide a rationale for each identified strength or weakness.
2. Quantification of Slick Area:	
4:15-5:00pm (45 mins)	**Charge Question 2.1:** Are the methods used to measure the surface area of the burning slick valid? If yes, explain why these methods are valid. If not, how could the validity of the area measurement methods be improved or more clearly described?
5:00-5:15pm	**Conclusion and Preparation for Day-2:** Mr. Rock, Facilitator, EnDyna

Tuesday, December 12, 2017

8:15am	**Arrive at EnDyna office**
8:30-8:45am	**Review of Agenda for Day-2:** Mr. Rock, Facilitator, EnDyna
8:45-9:30am (45 mins)	**Charge Question 2.2:** Are the numbers of images, heights, and angles from around the fire adequate for accurate area computations using the photogrammetric methods reported? Explain how the approach chosen could affect the validity of the methodology and results.
9:30-10:15am (45 mins)	**Charge Question 2.3:** Does the report adequately address the methods to account for errors from obstructions and limited angles/heights/distances? Explain how the methods used to account for errors could affect the validity or scientific merit of the methodology and results.
10:15-10:30am	BREAK
10:30-11:15am (45 mins)	**Charge Question 2.4:** Are the assumptions of the area algorithm input with respect to burning area of the slick clearly defined and appropriate (see Sections 2.1.1, 3.1.1, and 3.2.1)? If yes, explain why. If not, explain how those assumptions could be defined more clearly. Provide a rationale for your answer about the appropriateness of the assumptions of the area algorithm input with respect to burning area of the slick.
11:15-12:00pm (45 mins)	**Charge Question 2.5:** What are the strengths and weaknesses of the methods for the determination of the area(s) of the burning slick? Provide a rationale for each identified strength or weakness.
12:00-1:15pm	LUNCH (on your own)
3. BSEE Study Report:	
1:15-2:00pm (45 mins)	**Charge Question 3.1:** To demonstrate the technology proof of concept—Does the report adequately address the methodology to accurately calculate the volume of the entire slick given the differences in thicknesses throughout the entire slick being burned? Explain how this affects the validity or scientific merit of the methodology and results.
2:00-2:45pm (45 mins)	**Charge Question 3.2:** To demonstrate the technology proof of concept—Does the report describe with reasonable accuracy how burn volumes, burn rates, and burn efficiencies are computed? If yes, explain why these computations are described with

	reasonable accuracy. If not, how could the report describe these computations more clearly or with improved accuracy?
2:45-3:00pm	BREAK
3:00-3:45pm (45 mins)	**Charge Question 3.3:** To demonstrate the technology proof of concept—Are the limitations and uncertainties clearly identified and adequately characterized for the determination of burn volumes, burn rates, and burn efficiencies? If yes, explain why. If not, how could the limitations and uncertainties for the determination of burn volumes, burn rates, and burn efficiencies be described more clearly or characterized with improved accuracy?
3:45-4:15pm (30 mins)	**Charge Question 3.4:** To demonstrate the technology proof of concept—What are the strengths or weaknesses of the methods used for the computations? Provide a rationale for each identified strength or weakness.
4:15-5:00pm (45 mins)	**Charge Question 3.5:** To demonstrate the technology proof of concept—Are there any other conclusions that could be drawn that are not adequately addressed in the report? Are there any other issues or concerns with the validity of the methodology or results that were not included in the previous charge questions?
5:00-5:15pm	**Conclusion:** Mr. Rock, Facilitator, EnDyna

Attendees:

Dr. Smita Siddhanti, EnDyna, Facilitator
Ms. Amy Doll, EnDyna, Peer Review Lead
Mr. Ken Rock, EnDyna, Facilitator

Dr. Oscar Garcia-Pineda, Expert Peer Reviewer
Dr. Bill Lehr, Expert Peer Reviewer
Mr. Neré Mabile, Expert Peer Reviewer
Dr. Tom Weber, Expert Peer Reviewer

Presenter (Background on BSEE Study):
Ms. Karen Stone, BSEE, Oil Spill Response Engineer

Peer Review Panel Meeting "Ground Rules"

- An external peer review is intended to solicit individual reviewer feedback, to increase the independence of the peer review process.
- The panel is not asked to, and should not attempt to, form consensus or collective recommendations, ratings, or opinions, and panel reviewers must understand that they should provide individual feedback on the research product.
- Any BSEE staff that may attend the panel meeting can only provide background information on the research product to the peer reviewers, which can occur only during the panel meeting run by EnDyna, and at EnDyna's request.
- The panel meeting will not include discussion related to BSEE policy recommendations and decisions.

Peer Review Objective and Scope

[Excerpts from BSEE TO#10 Charge Document]

The objective of this panel-style peer review is for BSEE to receive comments from individual experts on the draft final report entitled, *Quantitative Measurement of In-Situ Burn (ISB) Efficiency and Rate*. This panel-style peer review is technical in nature, reviewing the methods, data quality, the strengths of any inferences made, and the overall strengths and limitations of the study.

BSEE Charge for the Scope of this Peer Review

BSEE has carefully defined the scope of this peer review for the draft final report in order to focus the peer review process effectively on BSEE's Charge Questions. Your written comments should stay within the BSEE scope defined below. It is important to remember that this panel-style peer review is technical in nature, reviewing the methods, data quality, the strengths of any inferences made, and the overall strengths and limitations of the study.

The scope of the peer review is focused on the methodology used in this study to determine burn volumes, burn rate, and burn efficiency. As such, the peer reviewers should focus on providing comments on the technical nature of the report. Because the review is technical in nature, the peer reviewers should <u>not</u> focus on editorial style.

Refer to the **BSEE Charge for the Scope of this Peer Review** provided above for an explanation of the focus of the peer review for this BSEE study report. During your review, you may refer to the entire report when developing your peer review comments on the methodology used in this study to determine burn volumes, burn rate, and burn efficiency. BSEE is <u>especially</u> interested in comments that focus on the <u>validity</u> or <u>scientific merit</u> of the methodology and that identify any significant weaknesses in the scientific information from the methodology. BSEE is <u>not</u> interested in suggestions for alternative approaches; the research for this study is completed.

7. APPENDIX C: BSEE's WRITTEN ANSWERS TO PEER REVIEWER QUESTIONS

The EnDyna Peer Review Lead compiled questions identified from the peer reviewer's initial written comments about the draft final report of the BSEE study entitled, *Quantitative Measurement of In-Situ Burn (ISB) Efficiency and Rate*. EnDyna's Peer Review Lead listed/paraphrased these questions, and submitted the questions to BSEE in four batches with the identity of the individual peer reviewers kept anonymous. EnDyna requested that BSEE provide additional information in writing for those peer reviewer questions so that EnDyna could distribute BSEE's written answers to all four peer reviewers in advance of the peer review panel meeting on December 11-12, 2017.

After receipt of BSEE's written answers to EnDyna's compiled list of peer reviewer questions, the EnDyna Peer Review Lead re-organized them by charge question and reformatted them in a more readable manner. BSEE's written answers to the peer reviewer questions are provided below.

BSEE's Written Answers to TO#10 Peer Reviewer Questions
for independent external peer review for draft final report,
Quantitative Measurement of In-Situ Burn (ISB) Efficiency and Rate

1. Quantification of Slick Thickness:

Charge Question 1.1: Are the methods used to measure the oil slick thickness throughout the entire length of the *in-situ* burn tests valid? If yes, explain why these methods are valid. If not, how could the validity of the oil slick thickness measurement methods be improved or more clearly described?

- **Did the methods/experiments used to measure the oil slick thickness throughout the entire length of the *in-situ* burn tests include a calibration test (e.g., testing under known variable thicknesses to validate calibration of acoustics system/transducers)?** (Garcia-Pineda 1.1)

  Yes. The lab measurements of the speed of sound as a function of temperature were performed with the travel path held constant for all temperatures.

- **Could a comparison of the results from the series of different burn tests be provided, in order to evaluate how well the results were correlated under similar circumstances?** (Garcia-Pineda 1.1)

  We can do this if desired, but did not perform these measurements of precision. See Figure 21 and 22 for a measurement of the accuracy.

- **Could BSEE clarify if the acoustic travel time measurements used harmonic mean sound speed, a mean sound speed, or some other value, to measure oil slick thickness? If harmonic mean sound speed was used, how was it calculated?** (Weber 1.1, 1.5, 3.2)

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The harmonic mean sound speed was not used for these measurements. We measured the temperature profile inside the slick during the burn which was used to calculate an average temperature inside the slick. This average temperature was then used to calculate the speed of sound based on the measurements of the speed of sound as a function of temperature determined from the lab measurements. Based on comparisons with the mass loss using the scale we believe this method is accurate to first order. We are interested in exploring alterations to this method in future work to improve the accuracy of the results.

- **Because each measurement of thickness seems smooth (although the oil/water interface can be dynamic during burning), could BSEE clarify whether some type of averaging was performed, and if so, could more information be provided to describe this process?** (Weber 1.1 and 3.2)

  The measured thickness of the oil slick shown in Figure 32 and Figure 52 in the Section 3.1.3 and 3.2.3 was smoothed by performing a moving average over 101 points. Since the data sampling rate is 2Hz (every 0.5 seconds), the thickness curve was averaged over 50 seconds.

Charge Question 1.2: Is the method to quantify the speed of sound in oil during *in-situ* burning operations valid? If yes, explain why the method is valid. If not, how could the validity of the speed of sound in oil quantification method be improved or more clearly described?

- **Can more information be provided about calibration accuracy or margin of error for the measuring equipment in the lab studies? In particular, how was calibration handled through different heat ranges for the slick**? (Mabile 1.2)

  During the lab measurements of the speed of sound as a function of temperature, the travel distance through the oil was held constant during the entire temperature range.

Charge Question 1.3: Does the report adequately address the measurement of varying slick thickness throughout the entire slick? If yes, explain why this measurement is adequately addressed. If not, how could these measurements be improved or more clearly described?

- **Did the methods used to measure the varying slick thickness throughout the entire slick account for how unburned residue could affect thickness and area measurements?** (Lehr 1.3)

  We did not account for the residue effects on the thickness or area measurements. We would like to pursue the correction to residue in the future.

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- **Did the methods used to measure the varying slick thickness throughout the entire slick account for the degree of uncertainty expected from time variations in water depth of the ROV?** (Lehr 1.3)

  Since we calculated the time difference between the bottom and top of the slick the change in travel time due to the variation of the water depth of the ROV was eliminated.

Charge Question 1.4: Does the report adequately address how the methodology for acoustic slick thickness measurements would be affected by waves and currents in open water conditions? Explain any issues or concerns that might affect the validity of this acoustical methodology in open water conditions.

- **Page 53 of the report mentions another project or other studies where slick thickness measurements were successful for wave heights of up to ~23 inches (greater than the freeboard of many booms used to contain oil)—should the panel review those other studies?** (Lehr 1.4)

  The report describing those data are publically available at https://www.bsee.gov/sites/bsee.gov/files/research-reports//1065aa.pdf. We mentioned those results to provide an indication of the sea states where these thickness measurements have been accomplished. We would like to perform ISB measurements in open water and various sea states.

- ~~**Can more details be provided about the ability to operate an ROV for acoustic slick thickness measurements under a range of sea state conditions?**~~ (Garcia-Pineda 1.4) OUT-OF-SCOPE

- **Could BSEE clarify if the lab studies made any effort to evaluate how acoustical oil slick thickness measurements would work with varying oil emulsions**? (Mabile 1.4 and 1.5)

  While we did not study emulsions during this project we do have primary data on emulsions collected from Ohmsett and brought back to our lab at room temperature. These emulsions were inadequate to determine a set of calibrations data as the water content was unknown and additional changes occurred during transport. Studying ISB and thickness measurements of emulsions is an important part of our plans for future work and successful implementation of these measurements in the field.

Charge Question 1.5: Are the assumptions of the oil thickness algorithm input clearly defined and appropriate (see Sections 2.2.4, 3.1.3, and 3.2.3)? If yes, explain why. If not, explain how those assumptions could be defined more clearly. Provide a rationale for your

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answer about the appropriateness of the assumptions of the oil thickness algorithm input.

- **Is more information available about the limitations and expected error ranges to evaluate the appropriateness of the assumptions of the oil thickness algorithm input (e.g., expected accuracy of degree of horizontal spatial averaging)?** (Lehr 1.5)

  We have not addressed the degree of spatial averaging over the acoustic beam width on this or other projects. The report describing our measurements of thickness from an ROV platform provides more information about beam width and its effect on thickness measurements in waves. For this application we were focused on developing the methods to determine burn rate and efficiency in a sea state 0 (calm water). For future applications we plan to build on the results from this project and our experience of measurements from ROV platforms in various sea states to measure the thickness of ISB of oil in various sea states and open water.

- **In order to evaluate the assumptions of the oil thickness algorithm input, more details about the image processing and how the planar homography was achieved are necessary, especially for the middle steps of the process—can more details about the image processing be provided?** (Garcia-Pineda 1.5)

  The planar homography was generated by selecting 4 points intersecting the plane of the water in each oblique image the pixels were used as "starting coordinates." For the burn vessel for instance, the 4 points were on the straight sections of the container in a square shape. Regardless of the scale the points were mapped to "destination coordinates" in the shape of a square, for instance x-y pixels 100,100; 100,300; 300,300; and 300,100.

  The compute homography computation built into matlab or built into opencv was used depending on the experiment. The means to do this is fairly common in image processing and using out of box methods is appropriate. The basic idea can be found at:
  https://math.stackexchange.com/questions/494238/how-to-compute-homography-matrix-h-from-corresponding-points-2d-2d-planar-homog

  The created homography method inputs the starting and destination coordinates and returns 3x3 matrix. The matrix can be used to warp the image so that the initial points are warped into the destination square. All the other points in the image lying in the same plane are also perfectly transformed (assuming a pinhole camera). If a lens correction was to be used it would be used prior to selecting the initial coordinates. It was not included for reasons it was considered a secondary phenomenon that could be checked later using the video of 30+ burns, the aperture of the cameras was kept

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relatively small, the focal length long this was considered a secondary issue.

The image was then warped and overlaid on the other images these were inspected quickly by eye. If the points selected as initial points indeed lie at the destination coordinates the water surfaces will align and nothing needed to be done further, if not a small correction would be made to the initial coordinates to make the final image align. This exercise was done primarily to set up the "birds eye view" transform to each image ahead of an experiment so a live area measurement could be attempted.

The ability to automate this process using a -*transform – compare – correct* method was gauged.

- **In order to evaluate the assumptions of the oil thickness algorithm input, can more details about the geometry of the camera set-up (heights, distances, angles) be provided, in particular, details about the geometry that worked best for accurate geo-rectification? Additionally, can more details about how the algorithm is capable of handling other conditions (camera lenses, field of view, obliqueness range) be provided?** (Garcia-Pineda 1.5 and 2.2)

  Since the project was research and scoping there were many hours of experimentation with the primary goal on the image side to save as much video footage as possible and use it to develop and perfect area methods using just the video. The cameras were set on tripods or mounted to nearby structures and elevated 4 to 15 feet over the fire surface and distances 12 ft to 100 ft away. The camera position and height was changed for each location but primarily distributed around the burn. Oblique angle and pixels on target were considered the most important. Any camera lens that can be corrected (chess board lines appear straight) can be used. The system is capable of detecting 100% burn area of the closed containers used in lab experiments, and the primary oil rate measurements are based on 100% area burn conditions.

  Much the experimentation and scoping was performed to figure out the best method for open water burning. For this applications the FOV and distance leads to pixels on target which is most important. The actual obliqueness range depends on surface roughness and boom height, (height of the walls of the container or containment ice in the lab) as these block the fire at low angles. Low angle cameras are more difficult to create a homography and produce a good warped image due to a pixel stretching multiplier between the initial and final imagery. The theoretical limitation is the ability to make sub-pixel identification of fiduciary marks, and then correcting the homography based on alignment of water level features between images. Practically, when the camera is moving, the water is not a perfect plane due to waves and the boom has a distinct height and the water level marks needed to make the homography "on the

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fly" are moving and changing then the limit seems to be around 25 degrees. The goal for the open water burn is to key in on features to make this low as possible.

- **Could BSEE clarify if the lab studies made any effort to evaluate how acoustical oil slick thickness measurements would work with varying oil emulsions?** (Mabile 1.4 and 1.5)

  While we did not study emulsions during this project we do have primary data on emulsions collected from Ohmsett and brought back to our lab at room temperature. These emulsions were inadequate to determine a set of calibrations data as the water content was unknown and additional changes occurred during transport. Studying ISB and thickness measurements of emulsions is an important part of our plans for future work and successful implementation of these measurements in the field.

- **Could BSEE clarify if the acoustic travel time measurements used harmonic mean sound speed, a mean sound speed, or some other value, to measure oil slick thickness? If harmonic mean sound speed was used, how was it calculated?** (Weber 1.1, 1.5, 3.2)

  The harmonic mean sound speed was not used for these measurements. We measured the temperature profile inside the slick during the burn which was used to calculate an average temperature inside the slick. This average temperature was then used to calculate the speed of sound based on the measurements of the speed of sound as a function of temperature determined from the lab measurements. Based on comparisons with the mass loss using the scale we believe this method is accurate to first order. We are interested in exploring alterations to this method in future work to improve the accuracy of the results.

- **Given that the thermocouples were fixed in place, how was the top of the slick determined for the temperature measurements (which were in turn required to calculate sound speed)?** (Weber 1.5 and 3.2)

  The top was chosen by visually observing the thermocouple which was at the surface of the slick prior to burning. See "Supplemental Information for DRAFT Final Report E15PC00005.pdf" for additional information.

Charge Question 1.6: What are the strengths and weaknesses of the slick thickness determination methods? Provide a rationale for each identified strength or weakness.

[no peer reviewer questions]

2. Quantification of Slick Area:

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Charge Question 2.1: Are the methods used to measure the surface area of the burning slick valid? If yes, explain why these methods are valid. If not, how could the validity of the area measurement methods be improved or more clearly described?

- ~~**Did the research team consider the option of measuring both thickness and slick area by subsurface instruments?**~~ (Lehr 2.1) OUT-OF-SCOPE

- **Can more information be provided to describe what ancillary inputs were required to perform planar homography (presumably altitude and orientation?)?** (Weber 2.1)

  Those were not used in the lab experiments and are not required. Only initial points pixel coordinates initial point x-y plane relative positions and destination pixel coordinates. Earlier experience in photogrammetry suggests using the camera pose and altitude and lat – lon position are applicable to open water applications at larger scale.

- **Can more information be provided to describe how the fire, or absence of fire, is detected in the images?** (Weber 2.1)

  The fire was identified by RBG pixel values, for example (fire = pixels > 170 red, and blue, green < red), formula changes based on fire intensity and oil. Also in conjunction prefilter with frame by frame change detection. Fire is dynamic. Accumulating magnitude of pixel changes highlights fire location. Dilation of pixels fills in small gaps in interior.

Charge Question 2.2: Are the numbers of images, heights, and angles from around the fire adequate for accurate area computations using the photogrammetric methods reported? Explain how the approach chosen could affect the validity of the methodology and results.

- ~~**What is the concept for the planned placement of cameras (number and location) during actual open water burns?**~~ (Lehr 2.2) OUT-OF-SCOPE

- **The report (page 40) states that distant cameras and lower resolution (150x150 pixels over fire area) provides sufficient accuracy, but does not provide the calculations used to justify this statement—are such calculations available for this study**? (Lehr 2.2)

  "The data suggests 150 x 150 pixels over the fire area can supply the same accuracy as images with five times as many pixels."

  It may be more accurate to say "The random error due to 150 x 150 pixel on fire as opposed to many times more than that is not much different." The systematic error due

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to identification of burn vs non-burn regions is more variable and seems to be "approach dependent" instead of "resolution dependent."

The claim is based on working with the data sets of different resolution and indicates the method used to identify burning from non-burning are more important than resolution for accuracy of the area measurement. The deification of burning has to do with the scale of the fire (big or small), oil type and lighting, and what indicators are used to distinguish burn area be distinguished from non-burn area. Small scale fires with gaps in the fire texture and burning of certain types of oil closer to gasoline spectrum that burn with transparent or white flame are harder to resolve from the background than large scale fires and hot burning thicker oils.

For the math, 150 pixels x 150 pixels gives a resolution that is not limiting as much as the error consideration has to do with the detection algorithm. The 150 x 150 pixel burn area means 22500 pixels total. If the area is circular, 22500 pixels implies a perimeter of about 532 pixels. If these pixels are incorrectly identified as either non-burning or burning that is just 532 / 22500 * 100% = 2.36%. In reality a partially filled pixel will not always be counted as burn area or non-burn area cameras so it is not likely a random error will identify all perimeter pixels wrong. The real issue is the systematic error.

- **In order to evaluate the assumptions of the oil thickness algorithm input, can more details about the geometry of the camera set-up (heights, distances, angles) be provided, in particular, details about the geometry that worked best for accurate geo-rectification? Additionally, can more details about how the algorithm is capable of handling other conditions (camera lenses, field of view, obliqueness range) be provided?** (Garcia-Pineda 1.5 and 2.2)

  Since the project was research and scoping there were many hours of experimentation with the primary goal on the image side to save as much video footage as possible and use it to develop and perfect area methods using just the video. The cameras were set on tripods or mounted to nearby structures and elevated 4 to 15 feet over the fire surface and distances 12 ft to 100 ft away. The camera position and height was changed for each location but primarily distributed around the burn. Oblique angle and pixels on target were considered the most important. Any camera lens that can be corrected (chess board lines appear straight) can be used. The system is capable of detecting 100% burn area of the closed containers used in lab experiments, and the primary oil rate measurements are based on 100% area burn conditions.

  Much the experimentation and scoping was performed to figure out the best method for open water burning. For this applications the FOV and distance leads to pixels on

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target which is most important. The actual obliqueness range depends on surface roughness and boom height, (height of the walls of the container or containment ice in the lab) as these block the fire at low angles. Low angle cameras are more difficult to create a homography and produce a good warped image due to a pixel stretching multiplier between the initial and final imagery. The theoretical limitation is the ability to make sub-pixel identification of fiduciary marks, and then correcting the homography based on alignment of water level features between images. Practically, when the camera is moving, the water is not a perfect plane due to waves and the boom has a distinct height and the water level marks needed to make the homography "on the fly" are moving and changing then the limit seems to be around 25 degrees. The goal for the open water burn is to key in on features to make this low as possible.

Charge Question 2.3: Does the report adequately address the methods to account for errors from obstructions and limited angles/heights/distances? Explain how the methods used to account for errors could affect the validity or scientific merit of the methodology and results.

[no peer reviewer questions]

Charge Question 2.4: Are the assumptions of the area algorithm input with respect to burning area of the slick clearly defined and appropriate (see Sections 2.1.1, 3.1.1, and 3.2.1)? If yes, explain why. If not, explain how those assumptions could be defined more clearly. Provide a rationale for your answer about the appropriateness of the assumptions of the area algorithm input with respect to burning area of the slick.

- **In order to evaluate if the errors are within an acceptable range, can the results (data and calculations) from the over 30 burns (noted on page 40) that were empirically used to determine error and verify the limits of forming an acceptable homography, be provided?** (Lehr 2.4 and 3.3)

  The focus of this project was to develop a viable method to measure the burn rate and efficacy using thickness and surface area rather than a rigorous measurement of the accuracy and precision. While we desire to perform these measurements of precision the detail of each burn was not specifically designed to achieve these results.

  We used a wide range of cameras settings in this study and plan on identifying the limit of the algorithm from the saved data from over 30 burns.

  An acceptable homography varies based on burn conditions. The set of conditions that were captured in the lab experiments will help determine the limits based on height of blockage around fire (in open water case, booms, in lab case, ice and container walls), wave height, and whether the fiduciary marker strategy or UAV camera pose and GPS pose or some combination is employed.

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- **In order to evaluate the assumptions of the area algorithm input with respect to burning area of the slick, can more information be provided about whether there was some normalizing of areas where odd shapes of fire occur? What was the margin of error or accuracy (e.g., estimation or "rounding off") associated with those odd fire shapes?** (Mabile 2.4)

  The noise and irregularities changed with lighting conditions and the type of oil burned. Sometimes analysis from multiple frames was averaged. One notable approximation was to note the number of pixels for 100% coverage of the container and round all areas above the container area to that number. The idea is that larger burning areas than the surface of the container are due to oil splashes out of the container than are not measured in the thickness accounting.

- **In order to evaluate the assumptions of the area algorithm input with respect to burning area of the slick, can more information be provided about the fire detection algorithm (step 6 above section 2.2) or examples of how an external length scale such as a boom are used to quantify the area (step 8 above section 2.2)?** (Weber 2.4)

  The external length scale is used the same as a ruler in a picture. If the picture is an overhead orthorectified view of a flat scene then converting ruler scale to length/pixel true dimensions including areas can be deduced. This technique is used in photogrammetric scenes.

Charge Question 2.5: What are the strengths and weaknesses of the methods for the determination of the area(s) of the burning slick? Provide a rationale for each identified strength or weakness.

[no peer reviewer questions]

3. BSEE Study Report:

Charge Question 3.1: Does the report adequately address the methodology to accurately calculate the volume of the entire slick given the differences in thicknesses throughout the entire slick being burned? Explain how this affects the validity or scientific merit of the methodology and results.

- **Could clarification be provided about when/if more than one transducer was used in any of the experiments?** (Lehr 3.1)

  Depending on the motion of the oil during the burn, we used one or more transducers to determine the thickness. Since all transducers were covered by the oil prior to the burning and while the burns covered 100% of the surface, we focused on identify the

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transducer that provide the best data throughout the entire burn.

Charge Question 3.2: Does the report describe with reasonable accuracy how burn volumes, burn rates, and burn efficiencies are computed? If yes, explain why these computations are described with reasonable accuracy. If not, how could the report describe these computations more clearly or with improved accuracy?

- **Why are there no error bars on any of the graphs or for any of the measurements?** (Lehr 3.2 and 3.3)

  We did not attempt to determine the precision of the measurement at this time, partly because each burn was unique and the ISB was a dynamic process. We have the data and from multiple "identical" burns and plan to determine the error bars in the future if the burns were close enough to the same.

  Figure 21 and 22 provide information about the accuracy by comparing the thickness from acoustic measurements with direct measurements of the mass loss throughout a burn and with the thickness prior to burning. Based on these data we estimate the acoustic measurement of thickness is accurate to within ~ 1 mm.

- **Could BSEE clarify if the acoustic travel time measurements used harmonic mean sound speed, a mean sound speed, or some other value, to measure oil slick thickness? If harmonic mean sound speed was used, how was it calculated?** (Weber 1.1, 1.5, 3.2)

  The harmonic mean sound speed was not used for these measurements. We measured the temperature profile inside the slick during the burn which was used to calculate an average temperature inside the slick. This average temperature was then used to calculate the speed of sound based on the measurements of the speed of sound as a function of temperature determined from the lab measurements. Based on comparisons with the mass loss using the scale we believe this method is accurate to first order. We are interested in exploring alterations to this method in future work to improve the accuracy of the results.

- **Because each measurement of thickness seems smooth (although the oil/water interface can be dynamic during burning), could BSEE clarify whether some type of averaging was performed, and if so, could more information be provided to describe this process?** (Weber 1.1 and 3.2)

  The measured thickness of the oil slick shown in Figure 32 and Figure 52 in the Section 3.1.3 and 3.2.3 was smoothed by performing a moving average over 101 points. Since the data sampling rate is 2Hz (every 0.5 seconds), the thickness curve

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was averaged over 50 seconds.

- **Given that the thermocouples were fixed in place, how was the top of the slick determined for the temperature measurements (which were in turn required to calculate sound speed)?** (Weber 1.5 and 3.2)

  The top was chosen by visually observing the thermocouple which was at the surface of the slick prior to burning. See "Supplemental Information for DRAFT Final Report E15PC00005.pdf" for additional information.

- **Was there smoothing or filtering of the thickness data, and if so, can more information provided on how this was done?** (Weber 3.2)

  The measured thickness of the oil slick shown in Figure 32 and Figure 52 in the Section 3.1.3 and 3.2.3 was smoothed by performing a moving average over 101 points. Since the data sampling rate is 2Hz (every 0.5 seconds), the thickness curve was averaged over 50 seconds.

Charge Question 3.3: Are the limitations and uncertainties clearly identified and adequately characterized for the determination of burn volumes, burn rates, and burn efficiencies? If yes, explain why. If not, how could the limitations and uncertainties for the determination of burn volumes, burn rates, and burn efficiencies be described more clearly or characterized with improved accuracy?

- **In order to evaluate if the errors are within an acceptable range, can the results (data and calculations) from the over 30 burns (noted on page 40) that were empirically used to determine error and verify the limits of forming an acceptable homography, be provided?** (Lehr 2.4 and 3.3)

  The focus of this project was to develop a viable method to measure the burn rate and efficacy using thickness and surface area rather than a rigorous measurement of the accuracy and precision. While we desire to perform these measurements of precision the detail of each burn was not specifically designed to achieve these results.

  We used a wide range of cameras settings in this study and plan on identifying the limit of the algorithm from the saved data from over 30 burns.

  An acceptable homography varies based on burn conditions. The set of conditions that were captured in the lab experiments will help determine the limits based on height of blockage around fire (in open water case, booms, in lab case, ice and container walls), wave height, and whether the fiduciary marker strategy or UAV camera pose and GPS pose or some combination is employed.

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- **Why are there no error bars on any of the graphs or for any of the measurements?** (Lehr 3.2 and 3.3)

  We did not attempt to determine the precision of the measurement at this time, partly because each burn was unique and the ISB was a dynamic process. We have the data and from multiple "identical" burns and plan to determine the error bars in the future if the burns were close enough to the same.

  Figure 21 and 22 provide information about the accuracy by comparing the thickness from acoustic measurements with direct measurements of the mass loss throughout a burn and with the thickness prior to burning. Based on these data we estimate the acoustic measurement of thickness is accurate to within ~ 1 mm.

Charge Question 3.4: What are the strengths or weaknesses of the methods used for the computations? Provide a rationale for each identified strength or weakness.

- **In order to evaluate weaknesses, could information on additional calculations, such as for signal to noise ratio from the acoustic measurements and view correction uncertainty using planar homography, be provided?** (Lehr 3.4)

  When the S:N of the acoustic measurements were low the reflection from the bottom of the slick became obscured by the electronic noise. In these cases we did not report a thickness. Since we collected data every 0.5 seconds having a low S:N periodically did not adversely affect our results. We did not keep track of the number of points with a S:N that was too low to provide useable data, but it was not frequent as can be seen in Figure 13. The most typical range was during boil over when the water below the surface boiled causing the bottom of the slick to fluctuate dramatically. In the open water boil over is not expected so we did not utilize our resources to study this phenomenon.

Charge Question 3.5: Are there any other conclusions that could be drawn that are not adequately addressed in the report? Are there any other issues or concerns with the validity of the methodology or results that were not included in the previous charge questions?

- **Was the mapping for the burning computation made solely with visual range cameras? Did the thermal imaging have any value for planar rectification?** (Garcia-Pineda 3.5)

  The thermal images can be rectified like the visual spectrum cameras and compared, since they ended up having blurry thermal boundaries they did not add additional information useful for the scope of this particular project. We plan to used thermal imaging in the future to determine of it can supplement the visible images. Any camera

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can be used if a homography can be constructed. Since thermal camera image heat, the shape of the fire could be used to rectify and align it with the shape of the fire from the visible cameras "on the fly."

8. APPENDIX D: PEER REVIEW MATERIALS PACKAGES

The peer review materials packages that were sent to the reviewers are attached separately.