BSEE Comment Response Document on the National Academy of Engineering, Science, and Medicine's (NASEM) Peer Review of the Naval Research Laboratory's (NRL) titled: Peer Review of Interim Report on Computational Fluid Dynamics Model for Predicting Wellhead Oil-Burning Efficiency at Bench and Intermediate Scales

Item #	PDF (p/54)	Report Page	Agree (A) Disagree (D) Noted (N)	Review Comment	Action	Final Response
1	14/54	1	N	Consensus conclusion of the committee is that the model developed is not adequate for predicting the combustion efficiency of wellhead flames.	Clarify scope of work in NRL's Final Report to BSEE	Noted. BSEE worked with NRL to develop a basic CFD model with experimental validation to study burn efficiencies at the bench- and intermediate-scales. This initial modeling phase was never intended to predict actual wellhead efficiencies.
2	14/54	1	D	Modeling approaches employed are not state-of-the-art.	Add section to define problem & objectives	BSEE disagrees. NRL employed well-established models to study the variables in question. State-of-the-art is not necessarily the correct modeling approach as state-of-the-art is not as applicable as state-of-practice. While state-of-the-art may imply more parameters in spray and combustion studies, they are generally meant to model simpler systems (smaller, more defined flow regimes, simpler fuels, etc.). The "state-of-the-art" of modelling wellhead fires doesn't actually exist beyone the few attempts made before this one, which are referenced within the report. State-of-practice packages allows practitioners in the oil spill response community to adopt the same commericially-available arcitectures. NRL will add a section to define the problem and research objectives.
3	13	1	N	...without a well-defined problem, moreover, it is not possible to evaluate the adequacy of the model.	Define problem within scope	Noted, however, BSEE requested that NRL develop a model able to fit any well being considered for IWI, not just Liberty. NRL was not mandated to examine a single condition but rather a broad domain. The Liberty project was a single example. NRL understood that this problem had a very broad scope of needs, and per BSEE's request, initally worked most available and relavent measurements.
4	13	1	N	Is the correct configuration for the multiphase flow considered? Specifically, is co-annular two-phase flow appropriate for representing wellhead oil flow?	None	Noted. See page 7-8 and 81 of report
5	14	2	D	What are the thermophysical and chemical properties of the crude oil? How are those properties captured, or not captured, by the simpler fluids used in the study?	None	Disagree. The reviewers may be mistaken by how much NRL used the "simpler fuels." Water and heptane are used for small-scale droplet measurements, but the larger scale burn efficiency measurements do use actual crude oil (and water as a standard of something that won't burn).
6	16	4	N	...the committee did not limit its discussions to those questions	The initial report will concisely spell out objectives of this specific research program, and how they fit into the long-term objectives of the overall program.	Noted. BSEE's charge questions corresponded with the long term objective of the program, not the immediate objective of the statement of work. NRL will concisely spell out the objectives of this specific research program, and how it fits into the long-term objectives of the overall program.
7	17	5	N	Buoyancy and Radiation	The final report will include a section that acknowledges the gaps in scaling, chemistry, soot, etc. However, note that NRL needed to focus on the lowest gaps per BSEE's instruction at this stage of the research effort.	Noted. Bouyancy and radiation should be included in a large domain study, but this was not such a large study. NRL understood the issue and the final report will include a section that acknowledges the gaps in scaling, chemistry, soot, etc., and that the effects bouyancy and radiation will be required for future research.

8	17	5	N	Relatedly, explanations for why the set of fuels was selected for study are limited, and the relevance of these fuels to the expected multicomponent crude oil is unclear.	NRL will describe why they used heptane in laboratory studies, which is chemically, thermodynamically, and mechanically more simple than crude oil.	Noted. N-heptane was not the primary fuel used, but was a useful fuel to measure droplet formation due to physical properties' similarities. Water served useful to examine exit flow patterns and as a standard "non-fuel." The crude oil used was sourced from the location most similar to that studied in the Boots and Coots report and the Hilcorp Production Plan. More oils would be both difficult to source and would be outside of the scope of this study. They would however, be interesting for further study. NRL will describe why they used heptane in laboratory studies in the final report.
9	17	5	D	Were the assumptions regarding wellhead conditions and two-phase wellbore flow (including film thickness and instability, liquid entrainment, and droplet diameter and its influence on wellhead ejection behavior) adequately characterized?	Include section in final report limiting the problem to annular and mist flows, which are most likely to ignite and produce and efficient burn.	BSEE disagrees. In the larger scale study, NRL showed that the lower flow rates produces more fall out. There seems to be a misunderstanding of annular and mist terminology - they are not interchanged. Other 2-phase flow regimes that might result from a worst case discharge will not burn, so they were not included in the study. NRL will include section to further define and limit the problem to annular and mist flows, which are most likely to ignite and produce an efficient burn. See report page 17.
10	18	6	D	The authors assume annular-mist flow behavior for the sake of brevity and applicability, as these sprays may atomize well. However, the pools or fountains emerging from lower speed flows may not burn well, as evidenced by the authors' experimental results.	Address context of work in the final report (scope).	Disagree. NRL did not make the type of flow based on brevity. The only flow regime that would be considered a candidate for efficient combustion was annular, and even annular flow can have low burn efficiency rates under certain cases. In the NASEM report, there is a misunderstanding of annular and mist terminology: the two are not interchangeable.
11	18	6	A	Weber numbers may be valid for the bench-scale simulations, it is unclear whether they are applicable for the actual wellhead.	None	Agree. We agree that it in unclear if Weber numbers are valid and applicable to the actual wellhead, which is the point of the study. The correlations do not apply because the flows are outside the validated range of the domain.
12	18	6	N	A fundamental and critical concern is the model used to generate the input conditions for the NRL model. The worst-case discharge (WCD) model from Hilcorp is proprietary (per the Hilcorp report, whose Appendix G is not provided). Thus, detailed data, such as the content listed in the Society of Petroleum Engineers Technical Report, including flow correlations and uncertainty ranges of the parameters used in the Hilcorp WCD model, are not provided for evaluation. The choice of modeling methods will affect outputs from the Hilcorp WCD model, which were used as input conditions for the NRL model. Perhaps it is possible for BSEE to provide input ranges used for the WCD model for the particular reservoir of interest in the NRL study so there is some control on the input, initial, and boundary conditions used with the NRL model.	Address in the scope section of the final report.	Noted. BSEE did not charge NRL with calculating or examining the worst case disharge (WCD).
13			A	Key expertise on WCD model building and wellbore hydraulics appears to have been lacking in the NRL Study.	Clearly define scope in final report	Agree. NRL will clearly define the scope in the final report.
14	18	6	N	Knowledge of the range of nondimensional parameters expected in multiphase wellbore flow and a review of the literature on the regimes of the transition flow in wellbores would help clarify how relevant the authors' assumptions are for the wellbore flow.	None	Noted; however, NRL was not charged with calculating or examining the WCD.
15	18	6	D	The condition and type of exit structure can affect the external flow, so the systems used in the modeling and experimental work require justification.	None	Disagree. BSEE/NRL discussed this, but because each well failure would cause different geometry, this cannot be predicted.
16	19	7	A	NRL interim report contains sufficient information to show that further development is needed based on the droplet dynamics and combustion data. Given the complexity of the overall problem, subprocess models must work in tandem, and it would have been preferable to provide sensitivity and uncertainty quantification of model assumptions, constants, and boundary and initial conditions as they relate to the ultimate objective of predicting burn efficiency.	Additional sensitivity analyses and uncertainty quantification will be conducted.	Agree. An additional sensitivity analysis and uncertainty quantification are warranted and will be recommended for inclusion in future research.

17	19	7	N	The sooting and liquid-phase coke particulate emission characteristics of crude oils are not well represented by n-heptane. Particulate generation and burnout will affect several critical physical and chemical transport mechanisms in the model, including the radiative energy balance. In addition, preferential evaporation of lighter components in crude oil may induce composition and thermal stratification in the mixture not captured by n-heptane, which affect combustion rates. CFD mixing and combustion models need to account for this stratification. While use of a surrogate may be a necessary approach for representing crude oils, the committee had considerable concern regarding how to appropriately develop and validate surrogates for studies of crude oil combustion. Developing a surrogate that could be reproduced by other members of the community for complementary studies would be valuable. Such a surrogate would need to reproduce the relevant properties of crude oil, including viscosities, surface tension, latent heat, boiling point, and heat of combustion. Existing crude oil distillation and chemical properties show the extent to which internal liquid cracking and gasification must vary (as a result of changes in distillation fractions with temperatures exceeding 350^{o}C) for oils located just tens of miles distant from one another. Much greater effort to characterize and understand the physicochemical property effects of crude oils on atomization and combustion will be needed if the proposed model is to be used for regulatory applications, as proposed by the sponsors.	None	Noted. NRL was not using n-heptane as a full-fledged surrogate, rather as a means to examine one type of behavior. We agree that heptane is not a high-sooting fuel. It was used as an initial step to examine spray behavior and to be able to execute a model with a fuel that has well-established chemistry (chemical kinetics/mechanism). Heptane was not meant to be used for validation of sooting/radiation behavior or effects. NRL is aware of the many problems associated with surrogate fuels and soot was not expected to be the same.
18	19	7	N	Further suggestions include studying effects of turbulent cross flow at typical Arctic wind speeds, and potentially leveraging data from large-scale pool fires with wind in the literature and perhaps available from other National Laboratories. However, understanding the cross flow and discharge ratios of these experiments compared with the NRL system is critical to their utility in model development.	Will help clarify by discussing limited nature of scope and proper framing of the problem	Noted. NRL will define limited scope of this research effort in the final report.
19	20	8	N	Another potential approach to validating the soot submodel is searching the literature for information on smoke point for similar fuels and reproducing the data for the surrogate (see Appendix D for suggested resources).	None	Noted. Normal (n)-heptane was not used as a surrogate for crude: it was used as a mechanical stand-in. Crude oil is not a single compound, rather it as a very wide variety of densities, viscosities, thermophysical properties and chemical constituents. For example, ANS alone as 13 distinct smoke points. (ref: OSRR #1036)
20	20	8	A	Assessing soot production and radiation with entrainment of air of different temperatures is an example of how to provide valuable information on the sensitivity of the submodels to such input parameters as the colder air temperatures expected in the Arctic. Sensitivity analysis is critical to understanding the effects of model input uncertainties.	Future research	Agree. The authors concur with the assessment of this charge question. While the current model incorporated a generic empirical model for soot formation for typical hydrocarbon fuels, the chemical complexity of crude oils warrants further research into this topic.
21	20	8	N	Were Lagrangian droplet dynamics and thermophysics adequately incorporated into the model? (See entire text.)	Uncertainty and sensitivities will be addressed as will discusion on effect of gravity on the droplets and fluid dynamics internal to the droplet.	Noted. The authors acknowleded that fluid dynamics internal to the droplet were not included in this initial model. The effect of gravity on the droplets will be important for simulating fallout. Uncertainty and sensitivities will be addressed as will discusion on effect of gravity on the droplets and fluid dynamics internal to the droplet.
22	20	8	D	Does the droplet injection model adequately simulate realistic diameters and velocities of two-phase, high-speed flows that would occur during a wellhead blowout event? (See entire text.)	None	Disagree. Droplet diameters and velocities were measured just above the laboratory burner inlet using NRL's phase Doppler anemometry, and are detailed in the report. However, additional effort will be required in future studies to obtain data closer to the injection location.
23	21	9	N	Does the validation process capture the controlling physical properties to a sufficient level of accuracy including transport and boundary conditions at the bench- and intermediate-scales for both gas-phase and two-phase turbulent spray?	Clearly define limited scope in the final report	Noted. NRL will define limited scope of this research effort in the final report.
24	21	9	A	The experiments provided some valuable information; however, they did not target validation of specific submodels.	None	Agree. This will be included in future research.

25	21	9	A	Radiation and soot formation submodels were not appropriately validated.	None	Agree; however, the scope of this initial effort was limited per BSEE's charge.
26	21	9	A	In particular, heptane is not a high-sooting fuel, and its sooting propensity is not expected to be consistent with that of wellhead fuels. Other fuels, such as a higher-sooting-propensity single component fuel (e.g., toluene) or mixtures of such a higher-sooting fuel with heptane, could be used to assess experimentally the effects of sooting propensity on the plume characteristics and observable features. (See the suggestion to create a soot surrogate fuel under the above discussion of soot and radiation models.)	None. Future research noted, but explain stepwise approach in final report.	Agree. The authors agree that heptane is not a high-sooting fuel. It was used as an initial step to examine spray behavior and to be able to execute a model with a fuel that has well-established chemistry (chemical kinetics/mechanism). Heptane was not meant to be used for validation of sooting/radiation behavior or effects.NRL will discuss their approach in the final report. The initial phase of this research was limited; however, we agree that the long term objectives and modeling for the Arctic need to take sooting into acount.
27	21	9	N	A fundamental concern is the primary assumption about using two-dimensional axisymmetric modeling for what is a highly three-dimensional physical flow.	None	Noted. Outside of the developing region of a jet, the assumption that the cross axis and circumferential turbulence is nearly equal can reasonably be applied.
28	21	9	N	Horizontal wind speeds in the Arctic are very high, and crossflow is expected to make wellhead flames highly nonaxisymmetric.	Include in front end of final report	Noted. NRL will define limited scope of this research effort in the final report.
29	21	9	A	The effects of turbulent mixing and the associated closure models (e.g., progress-variable scalar dissipation rate, mixture fraction dissipation rate, and cross-dissipation rates) also were not modeled and are not discussed in the interim report. Given the significant stratification expected with wellhead flames, these effects will very likely be important in determining the predicted combustion efficiency.	Add detailed discussion to final report	Agree. These effects were noted on p. 20 with a reference to the original paper on the subject. Details were omitted here for brevity. A more detailed discussion will appear in final report.
30	21	9	A	Other concerns relate to (1) transient heating and vaporization of the droplets, including the effect of shear-driven internal circulation within the droplet; (2) multicomponent mass diffusion within the liquid; (3) the importance of group droplet behavior in contrast to the assumption of isolated-droplet heating and vaporization; and (4) the mode of liquid-stream breakup (e.g., lobe-ligament-droplet cascade, lobe-hole bridge-ligament-droplet cascade, or some other sequence). Understanding the size of the droplets expected would help in assessing the importance of these transport mechanisms.	Add in scope section of final report	Agree. NRL will clearly define the scope in the final report.
31	21	9	N	Regarding the interpretation of the data, on page 61 of the interim report, the authors state that there were essentially no droplets outside r = +/–4 mm; however there were enough droplets to obtain a velocity reading, which appears to represent an inconsistency.	Will provide further explanation in final report.	Noted; however, this is not an inconsistency. It is due to the difference between velocity and droplet measurement validation within the data processing software. Beyond +/- 4 mm, the concentration drops off, such that there were not enough droplets with consistent sphericity to measure droplet diameter or to estimate a concentration. There were sufficient droplets to obtain velocities and sizes outside of 4mm, but the number of droplets measured to get those numbers was much lower. This will be clarified in the final report.
32	21	9	N	Additionally, the data plots lack error bars	None	Noted. For PDA measurements, it is difficult to decide what error bars should represent (actual "uncertainty" vs. experimental repeatability, and repeatability is difficult to assess).
33	22	10	A	The diffuse back-light illumination imaging was appropriately designed and provided meaningful insight and some data on the shape of the droplets and plume configuration, elucidating some of the initial breakup processes. The procedures are described adequately in the interim report. However, the report does not use the data for characterizing the droplet dynamics, other than showing one sample demonstrating a capability to track the droplets. Much more information—e.g., droplet velocity and size distribution—could be obtained by dynamically postprocessing the data. The interim report provides only preliminary results, with detailed analysis left for future investigations. An uncertainty analysis and assessment of accuracy are also absent.	NRL will complete this work and include it the in final report	BSEE agrees; however, this work had yet to be completed at the time of the interim report. The completed work and analysis will be included in the final report.

34	22	10	A	The committee reached general agreement that the Coherent Anti-Stokes Raman Spectrometry based Thermometry (CARS) method was competently applied and appropriate for the experiments and is well described in the interim report, with the caveat of suggesting improvements to the analyses. Specifically, the authors need to do a more thorough uncertainty analysis for their CARS measurements. This is a much more complex task than that for the previously discussed PDA measurement. Figure 45 in the NRL interim report appears to indicate that uncertainty analysis was done for data from the particular flame that was investigated, with 0.1 g/sec of ethane and 0.2 g/sec of heptane. The authors need to explain how they determined these uncertainties and include uncertainty bars on Figures 28 and 30 as well. They also need to explain clearly the differences between the averaged and single-shot measurements shown in Figure 53. For future CARS measurements in this group, it is essential to further develop the computational framework for analysis of single-shot CARS spectra.	None	Agree. The error bars are representative of the shot-to-shot variation. They are representative of the random error, not the bias error. Characterization of both is necessary to quantify the uncertainty of a measurement.
35	22	10	D	Figure 45 in the NRL interim report appears to indicate that uncertainty analysis was done for data from the particular flame that was investigated, with 0.1 g/sec of ethane and 0.2 g/sec of heptane.	None	Disagree. There are error bars in Fig 45, but they're not from an uncertainty analysis; rather, they represent the standard deviation of shot-to-shot variation in temperature.
36	22	10	A	Were the diagnostic methods (3-Color High-Speed Pyrometry) for the temperature measurements appropriately designed, clearly described, and adequate to capture temperature for the Gas Phase and Two-Phase Spray Flame?	Shortcomings of these methods will be acknowledged in the final report.	Agree. NRL will describe the shortcoming of the method including the lack of uncertainty that can currently be provided, and will include the calculated temperatures to provide an understanding of the flame behavior.
37	23	11	N	In the introduction to the interim report, the authors acknowledge the importance of scaling and discuss relevant dimensionless parameters, but they did not appropriately address this issue with analysis and experimental results, nor did they attempt to extrapolate the results between their two experimental scales or to full-scale conditions. A wealth of data from experiments performed by the authors could have been used to address scaling trends, but the authors did not perform this work, and did not use the experimental data well to examine the key assumptions about isolated droplet vaporization and heating and the effect of shear force on droplets. Are droplets batched together sufficiently to require the use of group theory for vaporization and burning? If nonspherical droplet shapes appear, shear could be one cause, thereby also being a likely cause of internal droplet circulation that would strongly affect heating and vaporization rates.	Address in scope section at front end of report.	Noted. This was not within the scope of this phase of the research.
38	23	11	N	A clear outline of the two-phase flow characterization is critical because it directly impacts burn efficiency, defined as the amount of liquid that falls to the ground. While the experiments were configured around annular flow of liquid coming out of a pipe with some spray in the center, the interim report does not clearly present the evidence for the assumption of this regime. This assumption is critical to the manner in which breakup occurs, so it is difficult to discuss impacts of the flow regime on atomization unless one knows whether there is annular or bubbly flow.	Address in scope section at front end of report.	Noted. The scope was limited to annular flow. NRL considered flow regimes and came to the assumption that bubble, slug, and churn flow will not produce produce a significant spray upon exiting because the gas velocity would be too slow and the liquid fraction would be too high. As such, upon their exit, it was assumed that they would produce significant liquid streams, splashing, and ligaments at the base of the plume to produce excessive pooling at the base. Such liquid flows would cause such low burn efficiency that they were not worth considering.
39	23	11	D	Justification for the assumption of annular flow is necessary,	Address in scope section at front end of report.	Disagree. The scope of the report is limited to annular flow. Bubbly flow will result in extremely poor burn efficiencies and would not be a candidate for wellhead ignition.
40	23	11	A	Another concern is whether there may be a water phase, which, in addition to making this a three-phase flow (water, oil, gas), would allow for the possible formation of oil-in-water and water-in-oil emulsions. Addressing how this would impact the modeling results would strengthen the model's applicability to other reservoirs as well, even if water intrusion is not a concern here. See Appendix D for literature on this topic.	Address in scope section at front end of report.	Agree. Water is always a concern; however, this was outside the scope of the research.
41	23	11	N	WCD model is proprietary, no details are provided. Information on pipe flow and wellbore model details and types are also missing, as is the application of key expertise in wellbore pipe flow and WCD modeling and experimental research. There is no way to verify whether the WCD volume is valid. Hence, a great deal of uncertainty is associated.	Address in scope section at front end of report.	Noted. This was outside the scope of this study.

42	24	12	D	The committee reached agreement that this research product does not adequately address how the wellbore flow would influence the behavior of the ejected spray plume. The initial experiments are foundational, but need to be expanded based on the current limited observations and limited conditions considered. Furthermore, the envelope of conditions needs to include the range of physical properties expected for crude oils, including highly volatile dissolution and water in the fluid.	Define scope in final report	Disagree. NRL was not charged with considering the infinitude of wellhead conditions. The final report will clearly define the scope of the research.
43	24	12	A	The committee has significant concern that the variability of oil composition dramatically affects many aspects of wellbore fires, including the pipe flow. If the goal is to create a model for a broad range of crude oils, the effects of the different thermophysical properties (e.g., surface tension, volatility, heat capacity) need to be considered.	Define scope in final report	Agree. While all this is valid, there is no way NRL could have considered all of this and worked with the many different types of crude oils.
44	24	12	A	Pipe geometry can likely play a role as well (e.g., shear flow, boundary layer effects). What are the geometric features of the wellbore exit (tapered pipe, flow bends)? Identifying the key pipe attributes required for the boundary conditions is a critical first step in designing the modeling approach and the experimental efforts. Additionally, detailed simulations of different pipe flow conditions are important to improve understanding of the behavior of the ejected spray plume. Emulsified materials may also be a relevant consideration (e.g., what water content is expected in the oil flows?).	Define scope in final report	Agree; however potential pipe boundaries at the exit are ouside the scope of this research.
45	25	13	N	Results of the intermediate-scale experiments show that the large droplets fall back to the ground because of their weight.	None	Noted. This is more likely drag in the flow, not weight.
46	25	13	D	But the experiments did not address the extent to which the droplet size distribution might be skewed by pipe exit geometry and drops appears to be significant.	Define scope in final report	Disagree. NRL was not charged with considering the infinitude of wellhead exit geometries.
47	25	13	D	At the same time, there is no direct and clear relationship between strain in the Large Eddy Simulation (LES) field and scalar dissipation in the flame; only a vague connection is made in flamelet theory. Unfortunately, a better model is not quite yet available.	None	Disagree. RANS was used, not LES.
48	25	13	D	The axisymmetric nature of the model may also pose some limitations.	None	Disagree. The model, as constructed, does not require axisymmetry. Specific validation simulations were conducted using an axisymmetric assumption, but this is not required.
49	25	13	N	The ambient wind conditions and directions can significantly affect the axisymmetric assumption.	Define scope in final report	Noted. Outside the scope of this initial research.
50	25	23	A	Gas-phase models may not be adequate with inherent evaporation/atomization assumptions. Droplet size distribution is input to the gas-phase combustion model and is a questionable choice. The postulated worst-case scenario, which assumes a slower gas velocity, leads to lower liquid atomization and lower burn efficiency. However, higher gas velocities could lead to more entrainment, and gas-phase combustion could become the controlling mechanism.	None. Include in future research.	Agree. The Rosin-Rammler distribution was used to initialize droplet diameters, which is a commonly-used practice for industrial calculations. The authors agree that verification of such an assumption is warranted.
51	25	13	D	The authors concluded that the remnant fuels on the ground are primarily from large liquid fragments, which were not entrained into the flame and settled because of heavier weight. However, the choice of surrogate fuel significantly affects this observation. The mismatch between the distillation range and particulate mass generation potential (and radiation effects) between the simpler surrogate fuels used for the NRL study and the actual crude properties will likely influence the predicted burn efficiency. Particulate mass generation should include all relevant crude oil combustion particles (e.g., liquid-phase coking, ash, sand, rock). The crude oil is expected to have higher particulate mass generation propensity. Large-scale coke particles will also contribute to the solid/liquid accumulation on the ground.	Clarify in the final report	Disagree. The reviewers are mistaken. Endicott crude oil was used to perform the fallout experiments. Furthermore, it is always most likely to be the heaviest components and fragments that would fall to the ground, and assumption of anything else would not be reasonable or likely.

52	25	13	D	The crude oil is expected to have higher particulate mass generation propensity. Large-scale coke particles will also contribute to the solid/liquid accumulation on the ground.	None	Disagree. Intermediate spray flames using Endicott crude oil were not that sooty. Their turbulent nature assured very efficient mixing.
53	26	14	A	At the core, there are concerns about the omission of certain information in the model—e.g., buoyancy, droplet size and velocity distributions, spray falling to the ground, and the potential for a fire whirl—that would have been relevant to the resulting burn efficiency.	Terms will be added to final report	Agree. The terms in the governing equations that control buoyancy effects were absent from the original document and were not considered for the small-scale flames considered in this study. The authors agree that this effect will be important for large-scale fires. The terms have been added to the revised document. Droplet size and velocity distributions were considered on p. 34 of the report.
54	26	14	A	At the core, there are concerns about the omission of certain information in the model—e.g., buoyancy, droplet size and velocity distributions, spray falling to the ground, and the potential for a fire whirl—that would have been relevant to the resulting burn efficiency. Additionally, even in the CFD model, a great deal of uncertainty in the submodels was not characterized. Submodel assumptions were not validated, and grid convergence and numerical artifacts also were not well characterized with respect to the submodels. It is therefore difficult to determine whether discrepancies exist and if so, whether they are attributable to numerics and resolution versus inadequacies in the model. In addition to validating the submodels, performing a sensitivity analysis would elucidate the impact of the different submodels on the end result. At this stage, this model is not predictive.	Terms will be added to final report	Agree. The terms in the governing equations that control buoyancy effects were absent from the original document and were not considered for the small-scale flames considered in this study. The authors agree that this effect will be important for large-scale fires. The terms have been added to the revised document. Droplet size and velocity distributions were considered on p. 34 of the report. Further, the authors agree that the model, in its current form, is not yet sufficient to to predict fallout from a wellhead burning event. Additional research and development efforts will be required.
55	26	14	D	However, the authors conducted no diagnostics other than imaging for intermediate scale.	None	Disagree. The burn efficiency measurements method was included in the appendix and a paper Dr. Brian Fisher published. Methods and results are already summarized in the report.
56	26	14	D	Extrapolating these results to the wellhead is problematic, in no small part because of differences in the behavior of the model oil chosen and crude oil.	Clarify in final report	Disagree. NRL used Endicott crude oil for the experiments.
57	27	15	A	The committee identified key concerns regarding the NRL modeling approach and experimental methods in three categories: 1. Gaps in the study approach and the assumptions chosen to represent the physical system of wellhead combustion limit the utility and accuracy of the approach and the model. 2. Several modeling approaches employed are not the state of the art. 3. Other modeling methods employed are the state of the art, but their related uncertainties and known weaknesses are not considered.	None. Could be considered in future research.	Agree. Models used in this study are commonly used for industrial calculations. The authors acknowledge that various specialized models exist that could provide improved predictive capability. These should be considered in future efforts.
58	28	16	D	An independent WCD model could be developed using data from the Liberty (Hilcorp report) and analog reservoirs (for which the Hilcorp report is insufficient).	Define scope in final report	Disagree. This is outside the scope of this research effort.
59	29	17	D	Naturally imposed external flows and induced flows were not considered.	Define scope in final report	Disagree. Naturally imposed external flows were considered and deemed to be dismissable for the purposes of the report. External and induced flows due to exit geometry or ambient conditions were not implemented for this study. Several assumptions of the parameter space were necessary, as mentioned in report page 7-8.
60	29	17	N	Additionally, the imposed external flows will lead to significant multidimensional behavior, and the flame/plume evolutions are not well-represented by axisymmetric assumptions.	None	Noted. Neither the model nor the testing assumes axisymmetry. The smalle-scale temperature measurements do have some of those assumptions. For the burn efficiency calculation, fallen droplets are interpolated where they are not collected, but they are weighted by direction. This was not highlighted in the report, as it was found that over the population of tests it did not change the results, and because there is detailed discussion in the published paper, which is included as an Appendix to the report.
61	34	22	D	Authors assume annular-mist flow behavior for the sake of brevity and applicability as these sprays probably atomize well.	Define scope in final report	Disagree. NRL studies this in depth, and did not make this assumption based on brevity.
62	34	22	D	...unclear if they would be applicable for the actual well-head.	Define scope in final report	Disagree. This report on the model and experiments were limited to bench- and intermediate-scales, not to actual well-head conditions.

63	40	28	D	I am somewhat concerned that the average temperatures that were reported were determined from averaged CARS spectra; the CARS spectra were average for 300 to 500 shots for the gas-phase flames, for example. In a gas flow with significant temperature fluctuations due to turbulence, the temperature determined from an averaged CARS spectrum will be biased towards lower temperatures because CARS signals will be stronger from the higher density, lower temperature gases. In extreme cases with very significant temperature fluctuations it will not be possible to extract an average temperature from an averaged CARS spectrum because it will not be possible to fit a theoretical single-temperature spectrum to the averaged CARS spectrum. For the spectra shown by the authors this does not seem to be the case, it appears the temperature fluctuations were not that severe. However, the rigorous way to analyze the CARS data is to fit the single-shot CARS spectra and then to determine the average temperature from the average of the single-shot temperatures.	Clarify in final report	Disagree. NASEM's statment is not correct -- NRL did not determine temperature from averaged spectra. NRL did exactly what the reviewer suggests -- they determined temperature from fits to single-shot spectra, and then calculated averages and statistics from the single-shot temperatures.
64	41	31	D	Obviously, n-heptane will not reveal the characteristics of the crude oil. The droplet formation and its dynamics can be quite different. Thus, burn efficiency data may not be extrapolatable.	Clarify in final report	Disagree. All burn efficiency measurements that were performed in this work were done with Endicott crude, not n-heptane.