WSPA

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President

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Clerk of the Board
California Air Resources Board
1001 I Street
Sacramento, California 95814

sent via e-mail to: http://www.arb.ca.gov/lispub/comm/bclist.php

Re: WSPA Comments on Second "15-Day Changes" to CARB Proposed Control Measure for Ocean-Going Vessels at Berth

To the Clerk of the Board:

This letter supplements comments previously submitted by the Western States Petroleum Association ("WSPA") on the California Air Resources Board's ("CARB") Proposed Control Measure for Ocean-Going Vessels at Berth ("Proposed Regulation") and its various amendments since its original release on October 15, 2019. WSPA is a non-profit trade association representing companies that explore for, produce, refine, transport and market petroleum, petroleum products, natural gas and other energy supplies in California and four other western states.

WSPA is providing these comments in specific response to the Second 15-Day Changes, and as part of a continuing effort to provide feedback on the Proposed Regulation. We incorporate our previous comments submitted on February 15, 2019; March 29, 2019; May 30, 2019; June 14, 2019; August 15, 2019; December 3, 2019; March 6, 2020; and May 1, 2020 by reference herein.

I. Summary of Concerns with Second 15-Day Changes

- The Second 15-Day Changes propose to extend the compliance start dates for container vessels, refrigerated cargo vessels, passenger vessels and roll-on roll-off ("ro-ro") vessels, but arbitrarily exclude tankers from any compliance schedule relief – based on an incorrect and unsupported claim that the tanker industry has "recovered" from the pandemic. The Second 15-Day Changes must be further revised to provide the lead time necessary for industry to recover from the nation's current severe economic recession and to conduct the feasibility studies necessary to ensure that new international safety standards are adequately considered, and that tankers are not put at unacceptable risk of explosion or other serious threats to safety.

- The proposed extension of the maximum "Innovative Concepts" compliance period from three years to five years in the Second 15-Day Changes fails to make "Innovative Concepts" a viable compliance alternative for tanker terminals.

- The proposed changes to the "interim evaluation" provisions fail to provide for the feasibility study critically needed for tankers before the Proposed Regulation is adopted.

- The Second 15-Day Changes assume no changes to projected emissions and economic activity in the face of the pandemic, relying instead on increasingly unrealistic and outdated assumptions about future business levels, emissions and potential environmental benefits of the amendments.

- A draft report for a CARB-commissioned study on real-world tanker emissions – "Emissions Evaluation of a Large Capacity Auxiliary Boiler on a Modern Tankers," dated March 2020 – was made available to WSPA for the first time in early July. The results indicate that Staff's tanker NOx emissions factor overstates the actual real-world factor by ***233***% and overstates the actual tanker PM2.5 emission factor by ***2,288%***. Despite these significant inaccuracies in Staff's assumptions, Staff have not accounted for the findings of this study in the Second 15-Day Changes.

II. Adjustments in Compliance Start Years for Regulated Vessels Should Not Arbitrarily Exclude Tanker Vessels

The Second 15-Day Changes propose adjusting the compliance start dates from 2021 to 2023 for container vessels, refrigerated cargo vessels, and passenger vessels, and from 2024 to 2025 for ro-ro vessels. *See* Proposed 17 C.C.R. § 93130.7(b). Staff noted that these proposed changes were made "in order to give registered entities additional time to prepare for compliance in light of the current economic downturn." CARB Second Notice of Public Availability of Modified Text and Availability of Additional Documents and/or Information ("Second Notice"), p. 9.

Staff's claims about "past recession events" do not appear to be supported by actual evidence in the record, nor is it clear what data justify Staff's assertions about the predicted future "recovery" of tanker vessel visits. Staff provide no evidence in the supporting materials for the Second 15-Day Changes to justify not also affording tanker vessels additional time for compliance. Indeed, in the Second Notice, Staff concede that all of the regulated vessel categories are seeing emissions reductions due to the serious reduction in economic activity and vessel visits attributable to the pandemic, and that all categories will take years "to recover to pre-recession visit levels." Second Notice, p. 18.

The only indication given as to why tankers are being treated differently came in Staff's slide presentation to the Board on June 25, 2020, during which Staff claimed that "we're already starting to see increases in crude imports in May and June, and demand is expected to continue recovering as more people resume normal daily operations. *See* Transcript of CARB Videoconference Meeting, June 25, 2020 ("Transcript"), p. 329:18-23. But Staff have yet to present the data on which they purport to rely, making it impossible to assess the veracity or accuracy of their statements. Moreover, since the June Board meeting, the resurgence of COVID-19 cases in California has prompted the re-imposition of strict state and local responsive measures, including widespread business closures. Under these circumstances, people are not resuming normal daily operations now or any time soon, and demand cannot be expected to continue recovering.

The available data show that, contrary to Staff's claim, the tanker industry is suffering significantly from the economic collapse right along with other vessel categories. Energy Information Administration ("EIA") data through April 2020 show that PADD 5 crude imports, which are dominated by California, have fallen 46% since December 2019. *See* https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=MCRIMP51&f=M. Furthermore, California Energy Commission data show that, compared to 2019 inputs during the same timeframe, California refinery crude inputs were down between 25 and 30 percent during May and June 2020, and down by 32% as of July 17.[1] As the graphs in Tab 2 show, though they are not as low in July 2020 as they were in early May 2020, week to week U.S. crude imports and

[1] CA Energy Commission Weekly Fuels Watch Report, accessed July 23, 2020 at https://ww2.energy.ca.gov/almanac/petroleum_data/fuels_watch/index_cms.html (attached at Tab 1).

exports in 2020 are still far below averages seen in 2019.[2] Total monthly visits of foreign tankers into Southern California ports and terminals went from 35 total visits in January 2020 to just 23 in May and in June 2020, a drop of 34.3%. These same tanker visits as of mid-July were at only 13, tracking for another very low month in July.[3] These data translate to significant reductions in tanker traffic not accounted for in Staff's tanker traffic projections or emissions totals, and stand in direct conflict to Staff's suggestion that the tanker industry is somehow "recovered" from the COVID-19 downturn.

But even if crude imports *were* seeing minor increases at times in May and June 2020, levels of recent activity do nothing to make at-berth capture and control feasible or safe for tanker vessels in the timetables provided in the Proposed Regulation. As we and others have explained in detail in numerous prior comments, the types of emissions capture and control equipment that would be required for tankers in the current Proposed Regulation still have not been proven safe and feasible in real-world operations with tankers at marine terminals. This makes both the original 2027/2029 compliance dates, and the accelerated 2025/2027 compliance deadlines from the First 15-Day Changes, unrealistic and potentially dangerous to attempt to meet, even if eventually determined to be feasible sometime in the future. Indeed, CARB heard undisputed public testimony at the June Board meeting that failing to follow stringent safety measures in managing gases in tanker cargo spaces at berth can lead to catastrophic explosion and loss of human life, as it has in prior real-world incidents. *See* Transcript, pp. 364-365 (testimony of Capt. Saul Stashower). This issue *alone* warrants giving ports and terminals additional time to conduct necessary feasibility studies in order to determine whether and how at-berth capture and control could be accomplished without risking people's safety.

The safety concerns associated with tankers – and the critical need to fully understand and account for them in *any* regulation impacting tankers – are further underlined in the new Sixth Edition of the International Safety Guide for Tankers and Terminals ("ISGOTT"), published in June 2020. *See* "International Safety Guide for Tankers and Terminals," International Chamber of Shipping, *et al.* (6th ed. 2020) (attached at Tab 4). The ISGOTT is "widely recognised as the definitive best practice guidance on tanker safety and pollution prevention" (ISGOTT, p. iii), and compliance with ISGOTT measures is mandated under several California statutes and regulations. *See* California Building Code (Title 24, C.C.R.), Ch. 31F (Marine Oil Terminal Engineering and Maintenance Standards ("MOTEMS") requiring marine oil terminals to meet various ISGOTT standards); 2 C.C.R. §§ 2340(c)(29), 2355(a) (State Lands Commission safety requirements for tanker operations to meet specified ISGOTT provisions). The latest ISGOTT now contains a new Chapter 8 with guidelines on due diligence steps that are to be taken before technologies not yet adopted in the tanker and terminal sector are applied to tankers. Among these diligence steps are directions to review a proposed technology's interface with the vessel's existing systems and processes, preparation of formal risk and impact assessment plans, a study of hazards presented by the new technology, evaluation of consistency with other industry and classification society standards, and analyses of tanker and terminal personnel safety. *See* ISGOTT, Ch. 8 (Tab 4). ISGOTT Chapter 8 highlights the critical need to assess alternative and emerging technology to ensure that its introduction does not negatively impact tanker and marine

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[2] *See* U.S. Energy Information Administration, Weekly U.S. Imports of Crude Oil and Weekly U.S. Exports of Crude Oil, Jan-Jul. 2020 (available at https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=pet&s=mcrimp51&f=m) (attached at Tab 2).

[3] July 2020, Marine Exchange of Southern California, "Major Ship Types By Count; 1-15 July 2020" (attached at Tab 3).

oil terminal safety. These important ISGOTT guidelines reinforce the safety concerns that we have documented throughout this rulemaking process.

In adhering to the ISGOTT guidance, tanker operators also rely on direction, guidance and approvals for regulatory and standards compliance from classification societies like the American Bureau of Shipping (ABS), a "recognized organization" by the United States Coast Guard and International Maritime Organization (IMO), and member of the International Association of Classification Societies (IACS) with consultative status at the IMO. The ABS has issued a guidance document relating to the numerous steps required to assess feasibility of any new technology on marine vessels before the technology can be adopted for real-world use, including engineering evaluations, risk assessments, engineering designs, creation of a manufacturing plan and quality assurance requirements, functional and model testing, prototype validation, systems integration testing, and ABS review. *See* ABS, "Guidance Notes on Qualifying New Technologies" (April 2017) (attached at Tab 5) ("ABS Guidance"). These safety, risk and other assessments cannot be short-cut or postponed for a later day. As the ABS Guidance points out, "[t]he qualification activities within each stage employ risk assessments and engineering evaluations that build upon each other in order to determine if the new technology provides acceptable levels of safety in line with current offshore and marine industry practice." In other words, we cannot simply skip to the "operational stage" without first completing the first stages in the ABS Guidance – *i.e.*, feasibility, concept verification, prototype validation and systems integration.

The record contains no indication that Staff have even reviewed the requirements of the ISGOTT or the ABS Guidance in preparing the Proposed Regulation, let alone evaluated whether the Proposed Regulation meets the due diligence and risk assessment requirements of the ISGOTT. Again, additional time should be provided in the compliance schedule for tankers, as it has for other classes of vessels, in order to allow Staff the time necessary to ensure that the Proposed Regulation takes the new ISGOTT guidelines and the ABS Guidance into consideration. These guidance materials also constitute new information that CARB must take into account in the analysis of hazard impacts in the Final Environmental Assessment for the Proposed Regulation.

In light of the catastrophic economy-wide impacts of the pandemic, and given the many serious safety concerns that the Proposed Regulation continues to raise for the tanker category, it would be arbitrary and capricious for CARB to adopt changes granting additional time for compliance for all other regulated marine vessel classes "in light of the current economic downturn," but not for tankers. Building in this extra time is crucial to ensuring that CARB does not rush to force impracticable and potentially dangerous requirements on tankers, terminals and ports.

III. The Extension of the Maximum "Innovative Concepts" Compliance Period from Three to Five Years Does Not Make It a Viable Compliance Alternative

The Second 15-Day Changes also propose extending the time during which an "innovative concept" may be used for compliance from a maximum of three years to a maximum of five years. *See* Proposed 17 C.C.R. §§ 93130.2(b)(21), 93130.17(a)(7). Staff remarked in the Second Notice that the proposed change is intended "to allow more certainty to innovative concept projects to be used for compliance under the Control Measure." Second Notice, p. 14.

As we and others have explained in prior comments, the proposed "Innovative Concepts" provisions do not provide the true compliance alternative stakeholders requested – *i.e.*, a compliance option ***in lieu of*** the currently unworkable requirement to install and operate yet-unproven at-berth capture and control systems. At best, an "Innovative Concept" would provide a temporary ***additional*** compliance obligation for stakeholders who choose the option, and after a defined maximum period of time, stakeholders *still* would be required to meet the requirement to install a capture and control system or provide shore power.

Changing this maximum time from three to five years does not address the core problems with the "Innovative Concepts" provisions. Most fundamentally, the Second 15-Day Changes fail to provide any relief from the running deadlines to install at-berth shore power or capture and control systems. Once one or more five-year "Innovative Concept" periods come to an end without CARB renewal (or during such a period if CARB decides to revoke an "Innovative Concept"), stakeholders then would become ***immediately*** subject to the default 2027/2025 deadlines to install a capture and control system. Far from providing more incentive to tanker terminals to choose the "Innovative Concept" option, a five-year project period would actually provide ***less*** incentive by increasing the amount of lost investment from funding the Innovative Concept over five years, while leaving the stakeholder with little or no time to install capture and control by the now-accelerated default regulatory deadlines.

IV. The Second 15-Day Changes to the Interim Evaluation Provisions Do Not Substitute for a Proper Feasibility Study

The Second 15-Day Changes also propose that in the envisioned "interim evaluation" of available control technologies and infrastructure for tankers and ro-ro vessels, CARB Staff will not only review "potential requirements for control technologies for use with bulk and general cargo vessels, and for ocean-going vessels at anchor," but now also the "control technologies" themselves. *See* Proposed 17 C.C.R. § 93130.14(d). Staff notes that "[t]his change clarifies that CARB will focus on what technologies are available, and will consider potential requirements for these specific vessel categories (rather than requirements for the control technologies themselves)." Second Notice, p. 14.

The proposed changes to subsection 93130.14(d) do not make the "interim evaluation" an adequate substitute for an actual tanker feasibility study done prior to adopting the Proposed Regulation. As discussed above, Chapter 8 of the June 2020 ISGOTT update provides that all aspects of a proposed technology's feasibility and safety – including hazards analyses, workability of the proposed interface with existing vessel systems, consistency with classification society and industry standards, and potential risks to tanker and shore-side personnel – must be reviewed ***before*** implementing the proposed technology, not ***after***. *See* ISGOTT, Ch. 8 (Tab 4).

Throughout this entire rulemaking, WSPA has been urging Staff to conduct a feasibility study concerning the viability and safety of installing capture and control systems for use with tankers, and to assess the results of this study before imposing requirements on tanker vessels. Yet, as currently proposed in the Second 15-Day Changes, section 93130.14(d) would require Staff to publish its report on tanker control technology by December 1, 2022 – nearly two years after portions of this Regulation become effective and a year after tanker terminals are required to submit terminal plans describing how they will comply with the Proposed Regulation.

The Second 15-Day Changes do not remedy the problem by directing that Staff evaluate both the "potential requirements" for control technologies and the "control technologies" themselves. We agree that these are critically important questions for determining whether and how tanker terminals can safely and feasibly comply with the Proposed Regulation. But they need to be answered ***before*** imposing mandatory compliance deadlines on stakeholders, not two years ***later***.

V. The Second 15-Day Changes Fail to Account for the Massive Economic Disruptions and Changes in Projected Emissions Attributable to COVID-19

In the Second 15-Day Changes, while Staff finally acknowledge the existence of the coronavirus pandemic, they believe it merits no changes at all to predictions of future economic and vessel activity, likely future emissions, or anticipated health outcomes. According to Staff, "[b]ecause the current circumstances are unique from past recession events, CARB staff expect there may be a reduction in emissions to continue over the next few years from reduced vessel visit activity but outcomes are unknown. Therefore we did not make changes to our inputs or methodologies at this time."[4] Second Notice, p. 18.

California law prohibits Staff from simply assuming away the most serious national economic calamity since the Great Depression. The Health and Safety Code authorizes CARB to adopt regulations only after finding that they are necessary, technologically feasible, and cost effective given the information made available to CARB Staff. Cal. Health & Safety Code §§ 39602.5(a), 43013(a). California Government Code Section 11346.3(c) further requires the Standardized Regulatory Impact Analysis (SRIA) in this rulemaking to conduct a full analysis of the potential of the Proposed Regulation to impact the creation or elimination of jobs, business, investment and innovation in the California economy, along with an accurate assessment of the health, safety and welfare benefits of the regulation. Cal. Gov. Code § 11346.3(c)(1).

Deciding that the most significant reduction of economic activity in a generation should result in ***zero*** change to Staff's pre-pandemic economic and emission assumptions defies logic and is plainly arbitrary and capricious. It allows this rulemaking to proceed on now increasingly inaccurate and unreliable projections of future tanker and other vessel activity in California's ports and terminals over the next several years. By refusing to account for reduced vessel activity in the future, Staff are choosing to rely on considerably overstated future emissions projections, leading to unrealistically high potential health impacts and, in turn, overstated promises of health benefits. Also, as discussed below, Staff's failure to disclose recent empirical data on tanker emissions has resulted in even further exaggerated and inaccurate projections for future tanker emissions.

A slower national and California economy over the next several years will very likely lead to reduced vessel trips and growth of vessel traffic over that period. Fewer vessel trips at California ports and terminals will mean lower at-berth emissions. At the very least, this could substantially change Staff's estimates of the potential health benefits of this measure (likely lower) and the cost-effectiveness of the Proposed Regulation (likely much less cost-effective). Staff are not entitled to ignore these impacts.

The public is not well-served when CARB Staff indulge exaggerated or unrealistic projections of future emissions. As the Legislature has pointed out, "[i]naccurate [emissions] inventories that do not reflect the actual emissions into the air can lead to misdirected air quality control measures, resulting in delayed attainment of standards and unnecessary and significant costs." *See* Cal. Health & Safety Code § 39607.3(d). Just because future "[o]utcomes are unknown" does not give CARB Staff permission to ignore them entirely. It is CARB's legal duty to accurately and fairly assess what impacts the coronavirus pandemic will have on future economic activity and vessel trips at California ports and terminals. Only then can CARB understand the true future emissions

[4] Notably, Staff found "past recession events" instructive when granting all vessel classes but tankers relaxed compliance schedules, but apparently of no guidance whatsoever in requiring changes to assumptions of future vessel activity, emissions or health outcome assumptions. *See* Second Notice, p. 18.

impacts of vessel traffic, and therefore, the potential impacts of the proposed measures on health and the actual cost-effectiveness of the Proposed Regulation.

VI. Staff Have Failed to Consider Making Changes to Tanker Emission Assumptions Considering the Compelling Results of a CARB-Commissioned Independent Study on Real-World Tanker Emissions

The Second 15-Day Changes fail to account for, or even acknowledge, a 2019 study commissioned by CARB on in-service tanker emissions – a study that shows a drastically lower emission factor for tankers than the factor on which Staff are currently relying. In 2019, CARB commissioned engineers at the University of California, Riverside, Bourns College of Engineering Center for Environmental Research and Technology ("CE-CERT") to conduct a study to evaluate real-world emissions from a modern tanker ship auxiliary boiler in the process of offloading fuel at berth. *See* Miller, W. et al., "Emissions Evaluation of a Large Capacity Auxiliary Boiler on a Modern Tanker," Draft Final Report, March 2020 (attached at Tab 6) ("CE-CERT Report"). CE-CERT conducted testing of the boiler in October 2019. The draft report, which is dated March 2020, was only made available to WSPA in early July 2020.

In our February 2019 comment letter on the Proposed Regulation, we expressed concern that the emission factors being used for tanker vessels "do not provide an accurate characterization of the emissions resultant from engines and boilers aboard a modern fleet" and specifically that the "stagnant PM emission factor is of particular concern." Staff was and still is using a 0.151 g/kWh PM2.5 emission factor and a 1.995 g/kWh NOx emission factor for tanker boilers in its emissions inventory for the Proposed Regulation. These emission factors are based on a 2002 report from Entec compiling data on vessels that were over 20 years old at that time, few of which are still in operation today.[5] Critically, Entec's boiler emissions factors were derived from boilers using heavy No. 6 fuel oil – ***not*** the cleaner burning, low sulfur distillate fuels CARB has mandated since 2008. *See* Entec Report, Ch. 2, p. 16 ("Emission factor measurement data relating to gas turbines and steam turbines are scarce in comparison to diesel engines and thus a greater uncertainty is associated with these factors. For steam turbines, all recent marine emission inventory studies have relied on US data from the early 1980s (US EPA, 1985 and Scott Environmental Technology Inc., 1981). Since no new data has been found in the literature and steam engines are in general being phased out, the same emission factors are proposed here.") The old NOx and PM2.5 emissions factors for heavy fuel oil are significantly higher than those for the low sulfur distillate fuels burned in tankers today.

Based on empirical observation, the CE-CERT Report observed tanker boiler PM2.5 emissions of 0.022 g/kg-fuel, which (using Staff's specific fuel consumption figure) converts to a PM2.5 emission factor of 0.0066 g/kWh.[6] ***This empirically-derived emission factor is 96% lower than the tanker PM2.5 emission factor still being used in Staff's assumptions***.

While it appears results on metals emissions still have yet to be added to the report due to COVID-19 related delays, its PM and NOx data appear to be complete and are directly relevant to the proposed regulation of tanker terminals in this rulemaking. Not only were the CE-CERT Report's

[5] *See* "Quantification of emissions from ships associated with ship movements between ports in the European Community," Entec UK Limited, Final Report (July 2002), Ch. 2 ("Entec Report") (available at https://ec.europa.eu/environment/air/pdf/chapter2_ship_emissions.pdf).
[6] The emissions factors derived here from the CE-CERT Report were derived using the same approach as the emissions factors calculated by Starcrest for CARB, in order to ensure the numbers cited herein can be meaningfully compared with the numbers used by CARB Staff.

conclusions based on empirical data from an actual in-service tanker vessel, they also are significantly instructive as to the broader tanker fleet calling at California ports and terminals. PM2.5 emissions from modern boilers are far less than those reflected in Staff's outdated PM2.5 emission factor largely due to changes in the type of fuel used and significant improvements to tanker boiler designs over 40 years. WSPA understands that CE-CERT discussed these findings with a representative from the boiler manufacturer (Alpha Laval) and was told that the improved nozzle designs used in current marine auxiliary boilers and the use of distillate fuel markedly reduced PM2.5 emissions due to less fouling and finer droplets.

If the CE-CERT Report's empirically derived emission factor were used in Staff's emissions estimates for tankers, the projected share of statewide ocean-going vessel ("OGV") PM2.5 emissions attributable to tanker vessels would fall from 50% to 20%. Yet at the June 25 Board hearing, Staff's slide presentation continued to misrepresent tankers' share of overall OGV PM2.5 emissions as 50%. At the June 25 hearing, Staff repeatedly cited this 50% number as an important basis for not adjusting compliance timelines or other requirements in the Proposed Regulation for tanker vessels.

Similarly, the CE-CERT Report observed real-world tanker boiler NOx emissions to be 0.858 g/kWh, which is *57% smaller* than the obsolete 1.995 g/kWh factor used by CARB that is based on the 40-year-old study. As with PM2.5, CARB is greatly overestimating the NOx emissions associated with tankers, and thus inflating the associated health benefits. The table below summarizes the differences in the emissions factors measured by the CE-CERT and those used by CARB.

Source	NOx (g/kWh)	PM2.5 (g/kWh)
CE-CERT	0.858	0.0066
CARB	1.995	0.151
Staff Emissions Overstated By	233%	2,288%

The CE-CERT Report establishes that Staff's NOx and PM2.5 assumptions incorrectly overstate actual tanker auxiliary boiler emissions, overstating actual NOx by 233% and overstating actual PM2.5 by a whopping ***2,288%***. Thus, the results of the CE-CERT Report must be assessed and incorporated into this rulemaking, and Staff's grossly overestimated PM2.5 and NOx emission factors must be corrected.

Also, the CE-CERT Report leads to potential questions about the validity of other Staff assumptions regarding tanker emissions and the resulting projections of health impacts. Together with refining its estimates of future economic and vessel activity as discussed above, Staff must incorporate these new emissions assumptions (and any other corrected emissions assumptions) into their overall analysis of anticipated future emissions levels, cost effectiveness calculations, and other variables dependent on the tanker emissions estimates.

Regardless of what conclusions are to be drawn from the Report, Staff has a legal duty to disclose and discuss the Report's findings. If Staff believe it is necessary to await a final version of the Report or solicit additional vessel testing before addressing the new emission data in this rulemaking, Staff should delay finalizing the Proposed Regulation.

* * *

WSPA stands ready and willing to assist Staff in doing the hard work necessary to complete a feasibility study, so that we may determine whether at-berth capture and control for tankers can be accomplished safely and in accord with the newest international tanker standards. ***But if this work is not properly completed, lives will be put at risk***. We remain deeply concerned that Staff have now submitted two revisions of the Proposed Regulation without adequate consideration of the significant health and safety issues posed, and without building in the time necessary for a feasibility study for tankers. This study must be done before imposing compliance mandates on ports and terminals, not years later. In the meantime, Staff cannot pretend that an unprecedented worldwide pandemic will have *no* impact on future economic activity or emissions. Staff must take the time needed to assess the serious economic impacts of COVID-19 and what it will mean in terms of true future emissions from OGVs. Stakeholders and the public deserve to have this rulemaking informed by a full and fair evaluation of the facts as they stand today, not as Staff might have understood them a year ago.

Sincerely,

Attachments

Western States Petroleum Association
Comments on Second 15-Day Changes to At Berth Regulation

List of Attachments

Tab	**Document**
1	California Energy Commission Weekly Fuels Watch Report, accessed July 23, 2020, https://ww2.energy.ca.gov/almanac/petroleum_data/fuels_watch/index_cms.html
2	U.S. Energy Information Administration, Weekly U.S. Imports of Crude Oil and Weekly U.S. Exports of Crude Oil, Jan-Jul. 2020, https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=pet&s=mcrimp51&f=m)
3	Marine Exchange of Southern California, "Major Ship Types By Count; 1-15 July 2020" (July 2020)
4	International Chamber of Shipping, *et al.*, "International Safety Guide for Tankers and Terminals," (6^{th} ed. 2020)
5	ABS, "Guidance Notes on Qualifying New Technologies" (April 2017)
6	Miller, W. *et al.*, "Emissions Evaluation of a Large Capacity Auxiliary Boiler on a Modern Tanker," Draft Final Report (March 2020)

California Energy Commission Weekly Fuels Watch Report

These numbers are based on reports from California refineries, and are subject to refinery revision and Energy Commission verification.

California Weekly Refinery Production and Stocks Levels (Thousands of Barrels)

Refinery Input

Production Type	05/08/2020	05/01/2020	Percent Change	One Year Ago	Percent Change

California Energy Commission Weekly Fuels Watch Report

These numbers are based on reports from California refineries, and are subject to refinery revision and Energy Commission verification.

California Weekly Refinery Production and Stocks Levels (Thousands of Barrels)

Refinery Input

Production Type	05/15/2020	05/08/2020	Percent Change	One Year Ago	Percent Change
Crude Oil	7,890	7,472	5.6%	11,355	-30.5%

California Energy Commission Weekly Fuels Watch Report

These numbers are based on reports from California refineries, and are subject to refinery revision and Energy Commission verification.

California Weekly Refinery Production and Stocks Levels (Thousands of Barrels)

Refinery Input

Production Type	05/22/2020	05/15/2020	Percent Change	One Year Ago	Percent Change
Crude Oil	7,857	7,890	-0.4%	11,302	-30.5%

California Energy Commission Weekly Fuels Watch Report

These numbers are based on reports from California refineries, and are subject to refinery revision and Energy Commission verification.

California Weekly Refinery Production and Stocks Levels (Thousands of Barrels)

Refinery Input

Production Type	05/29/2020	05/22/2020	Percent Change	One Year Ago	Percent Change
Crude Oil	7,730	7,857	-1.6%	12,168	-36.5%

California Energy Commission Weekly Fuels Watch Report

These numbers are based on reports from California refineries, and are subject to refinery revision and Energy Commission verification.

California Weekly Refinery Production and Stocks Levels (Thousands of Barrels)

Refinery Input

Production Type	06/05/2020	05/29/2020	Percent Change	One Year Ago	Percent Change
Crude Oil	8,088	7,730	4.6%	12,306	-34.3%

California Energy Commission Weekly Fuels Watch Report

These numbers are based on reports from California refineries, and are subject to refinery revision and Energy Commission verification.

California Weekly Refinery Production and Stocks Levels (Thousands of Barrels)

Refinery Input

Production Type	06/12/2020	06/05/2020	Percent Change	One Year Ago	Percent Change
Crude Oil	8,304	8,088	2.7%	11,500	-27.8%

California Energy Commission Weekly Fuels Watch Report

These numbers are based on reports from California refineries, and are subject to refinery revision and Energy Commission verification.

California Weekly Refinery Production and Stocks Levels (Thousands of Barrels)

Refinery Input

Production Type	06/19/2020	06/12/2020	Percent Change	One Year Ago	Percent Change
Crude Oil	8,413	8,304	1.3%	11,671	-27.9%

California Energy Commission Weekly Fuels Watch Report

These numbers are based on reports from California refineries, and are subject to refinery revision and Energy Commission verification.

California Weekly Refinery Production and Stocks Levels (Thousands of Barrels)

Refinery Input

Production Type	06/26/2020	06/19/2020	Percent Change	One Year Ago	Percent Change
Crude Oil	8,698	8,413	3.4%	11,710	-25.7%

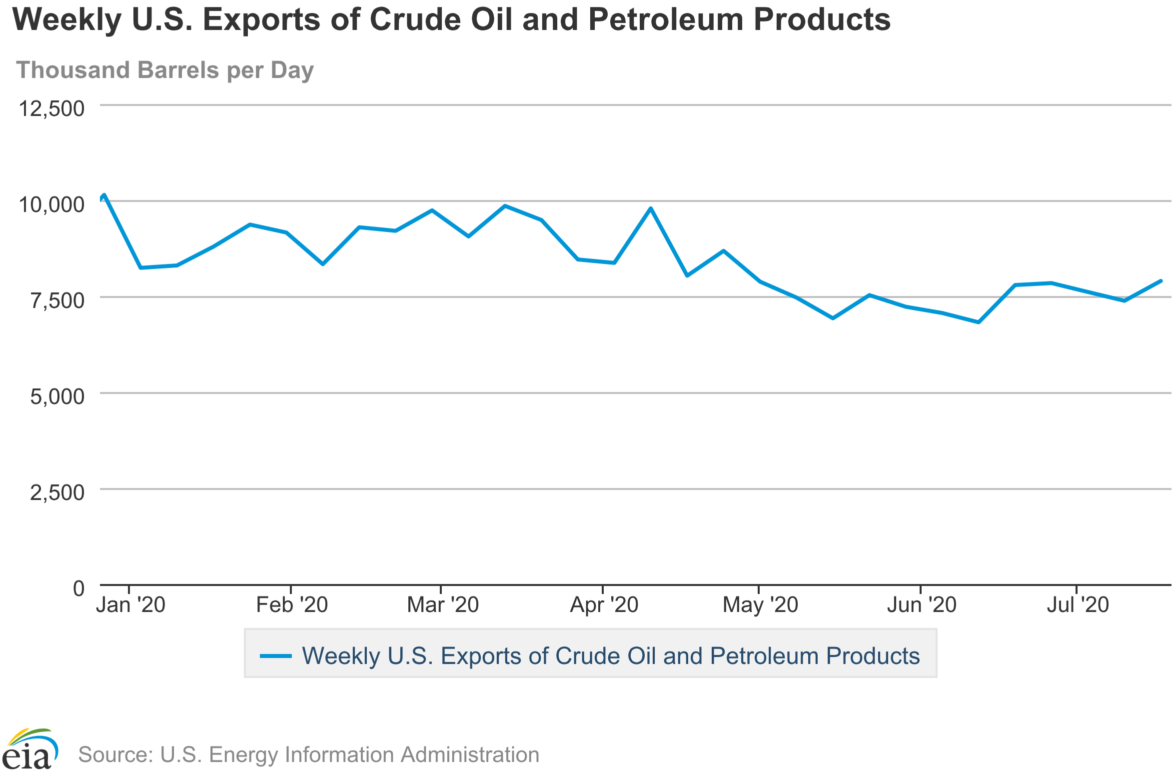
California Energy Commission Weekly Fuels Watch Report

These numbers are based on reports from California refineries, and are subject to refinery revision and Energy Commission verification.

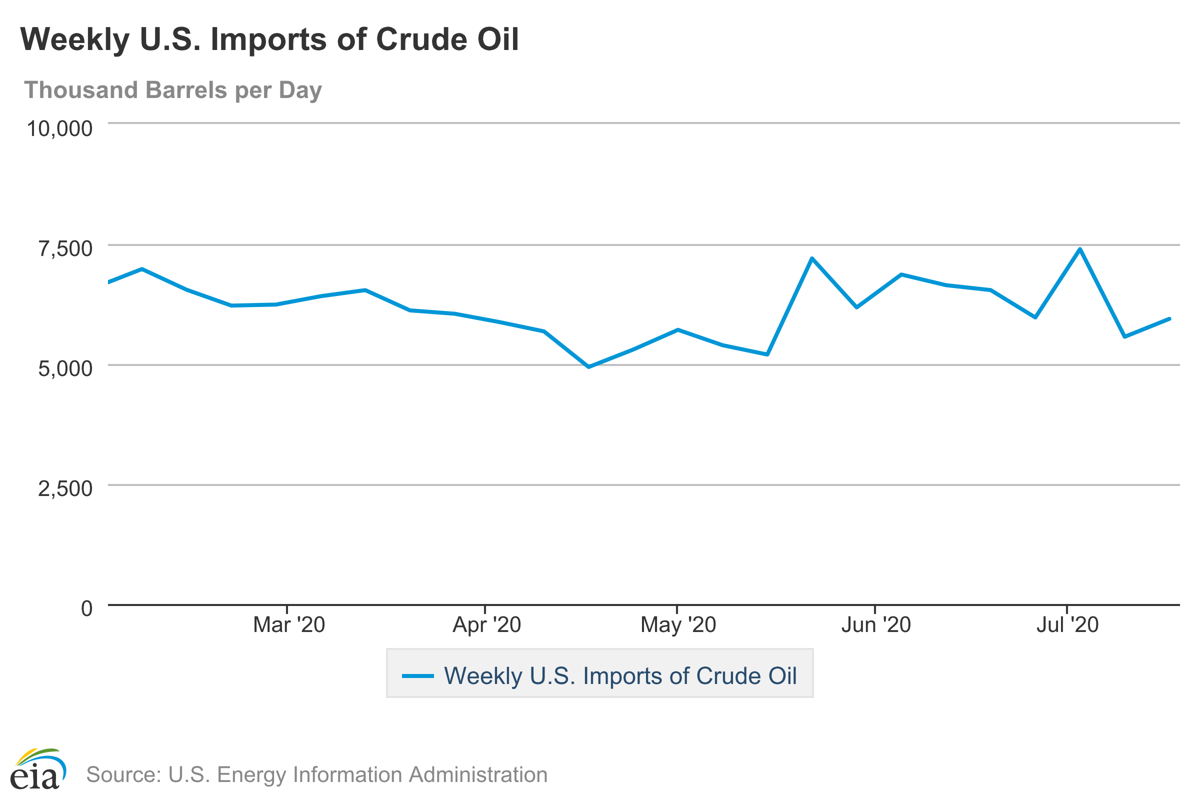
California Weekly Refinery Production and Stocks Levels (Thousands of Barrels)

Refinery Input

Production Type	07/17/2020	07/10/2020	Percent Change	One Year Ago	Percent Change
Crude Oil	8,293	8,597	-3.5%	12,189	-32%



Source: U.S. Energy Information Administration



Weekly U.S. Imports of Crude Oil
Thousand Barrels per Day
10,000
7,500
5,000
2,500
0
Mar '20
Apr '20
May '20
Jun '20
Jul '20
Weekly U.S. Imports of Crude Oil
Source: U.S. Energy Information Administration

Major Ship Types by Count
1-15 July 2020

15-Jul-20							
2020	2020	2020	2020	2020	2020	**2020**	
January	February	March	April	May	June	**July**	
Actual Ship Count							
Actual	Actual	Actual	Actual	Actual	Actual	**Actual**	**Type of Ship**
35	33	34	35	23	23	**13**	**Foreign Tankers**
172	135	145	156	132	153	**86**	**Container Ships**
5.5	4.7	4.7	5.20	4.4	5.1	**5.7**	**Container Ships per day**
16	18	22	14	9	6	**3**	**Vehicle Ships**
40	31	21	0	0	0	**0**	**Passenger Ships**
19	15	24	18	10	21	**9**	**Bulk Carriers**
6	16	10	1	20	16	**3**	**General Cargo**
58	47	50	94	42	37	**23**	**Bunkers Only**
411	344	371	394	294	305	**163**	**Total**
13.3	11.9	12.0	13.1	9.5	10.2	**10.9**	**Ships/day**

			Day of Current Month					
Days in 2018-2019			**15**			Container ships per day average 2018 - 2019		
730	**Ships per day by type**					5.67		
Ships per day Ship Count								
2018-2019 Average	January	February	March	April	May	**June**	July	**Type of Ship**
1.4	1.1	1.1	1.1	1.2	0.7	**0.8**	**0.9**	**Foreign Tankers**
Color-coding is relative to 2018-2019 average								**Container Ships**
5.7	5.5	4.7	4.7	5.2	4.3	**5.1**	**5.7**	**Container Ships per day**
0.6	0.5	0.6	0.7	0.5	0.3	**0.2**	**0.2**	**Vehicle Ships**
1.0	1.3	1.1	0.7	0.0	0.0	**0.0**	**0.0**	**Passenger Ships**
0.7	0.6	0.5	0.8	0.6	0.3	**0.7**	**0.6**	**Bulk Carriers**
0.5	0.2	0.6	0.3	0.0	0.6	**0.5**	**0.2**	**General Cargo**
1.2	1.9	1.6	1.6	3.1	1.4	**1.2**	**1.5**	**Bunkers Only**
12.5	13.3	11.9	12.0	13.1	9.5	**10.2**	**10.9**	**Ships/day**

ISGOTT

International Safety Guide for Oil Tankers and Terminals

Sixth Edition

International Chamber of Shipping
Shaping the Future of Shipping

OCIMF 1970 50 2020

IAPH
International Association of Ports and Harbors

First Published 1978, Second Edition 1984, Third Edition 1988, Third Edition Revised 1991, Fourth Edition 1996, Fifth Edition 2006, Sixth Edition 2020

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The International Chamber of Shipping (ICS) is the principal international trade association for the shipping industry, representing shipowners and operators in all sectors and trades.

ICS membership comprises national shipowners' associations in Asia, Europe and the Americas whose member shipping companies operate over 80% of the world's merchant tonnage.

Established in 1921, ICS is concerned with all technical, legal, employment affairs and policy issues that may affect international shipping. It represents shipowners with the various intergovernmental regulatory bodies that impact on shipping, including the International Maritime Organization (IMO).

ICS also develops best practices and guidance, including a wide range of publications and free resources that are used by ship operators globally.

Founded in 1970, the Oil Companies International Marine Forum (OCIMF) is a voluntary association of oil companies having an interest in the shipment and terminalling of crude oil, oil products, petrochemicals and gas, and includes companies engaged in offshore marine operations supporting oil and gas exploration, development and production.

Our vision is a global marine industry that causes no harm to people or the environment.

Our mission is to lead the global marine industry in the promotion of safe and environmentally responsible transportation of crude oil, oil products, petrochemicals and gas, and to drive the same values in the management of related offshore marine operations. We do this by developing best practices in the design, construction and safe operation of tankers, barges and offshore vessels and their interfaces with terminals and considering human factors in everything we do.

Founded in 1955, the International Association of Ports and Harbors (IAPH) is a non-profit-making global alliance of 170 ports and 140 port-related organisations covering 90 countries. Its member ports handle more than 60 percent of global maritime trade and around 80 percent of world container traffic. IAPH has consultative NGO status with several United Nations agencies. In 2018, IAPH established the World Ports Sustainability Program (WPSP). Guided by the 17 UN Sustainable Development Goals, it aims to unite sustainability efforts of ports worldwide, encouraging international cooperation between all partners involved in the maritime supply chain. WPSP (sustainableworldports.org) covers five main areas of collaboration: energy transition, resilient infrastructure, safety and security, community outreach and governance.

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Foreword

I am very pleased to introduce the revised Sixth Edition of the *International Safety Guide for Oil Tankers and Terminals*, or *ISGOTT* as it is generally known throughout the global tanker industry and amongst the Member States of the UN International Maritime Organization (IMO).

ISGOTT, first published in 1978, is now widely recognised as the definitive best practice guidance on tanker safety and pollution prevention, and is a perfect example of the good cooperation that exists between the IMO and the shipping industry the Organization regulates. The authors of this major publication – the International Chamber of Shipping (ICS), the Oil Companies International Marine Forum (OCIMF) and the International Association of Ports and Harbors (IAPH) – all enjoy consultative status with the IMO and contribute significantly to its work through their active participation at IMO meetings.

I believe that a reason why *ISGOTT* has endured, and is so highly regarded, is the vital complementary role it plays in working alongside the comprehensive framework of global shipping regulation that has been adopted by the IMO to help ensure safe and pollution-free ship operations.

Global maritime regulations, enforced by Flag States, are vital for ensuring that all ships, regardless of flag, can operate safely and efficiently wherever in the world they are trading. However, further detailed guidance on best operational practice is leveraged from the vast experience of industry professionals. Industry publications such as *ISGOTT* are therefore crucial for ensuring that the aims and objectives of IMO instruments, such as the MARPOL and SOLAS Conventions, are achieved in real life.

The safety record and the environmental performance of the tanker industry has improved substantially since the adoption by the IMO of its many Conventions and Codes. This impressive improvement in performance has not been delivered by regulation alone. It is a testimony to the good practices deployed, and constantly refined, by the industry itself and the dedication and huge professionalism of the seafarers and other personnel it employs.

This firm commitment by the industry to continuous improvement is a concept fully embraced by the IMO's ISM Code, and I believe this is clearly demonstrated by the industry's ongoing efforts to keep *ISGOTT* updated.

I fully support the industry-wide collaboration that has made this new edition of *ISGOTT* possible. This is crucial to ensuring that the maritime industry will not only contribute to maintaining and further improving its excellent safety record and reducing its environmental impact, but will also bring us ever closer to the ultimate goal of zero accidents.

Kitack Lim
Secretary-General
International Maritime Organization

Introduction to the Sixth Edition

Effective management of health, safety and environmental protection is critical to the tanker and terminal industry and the *International Safety Guide for Oil Tankers and Terminals (ISGOTT)* has become the standard reference on the safe operation of oil tankers and the terminals they serve.

ISGOTT was first published in 1978 by combining the contents of the *Tanker Safety Guide (Petroleum)* published by the International Chamber of Shipping (ICS) and the *International Oil Tanker and Terminal Safety Guide* published on behalf of the Oil Companies International Marine Forum (OCIMF). This revision of *ISGOTT* updates and replaces the prior Fifth Edition that was published in 2006 and has been reviewed by OCIMF and ICS together with the International Association of Ports and Harbors (IAPH). In addition, support has also been provided by other industry associations including the International Association of Independent Tanker Owners (INTERTANKO), the Society of International Gas Tanker and Terminal Operators (SIGTTO) and the Society for Gas as a Marine Fuel (SGMF), as well as specialists in topics such as human factors.

Through the combined effort of multidisciplinary subject matter experts from these industry leading organisations, this publication has been enhanced to ensure that it continues to reflect current best practice and legislation and, as a result, will maintain its position as a definitive reference for the safe operation of oil tankers and the marine terminals they visit.

This Sixth Edition encompasses the latest thinking on a range of topical issues including gas detection, the toxicity and the toxic effects of petroleum products (including benzene and hydrogen sulphide), the generation of static electricity and stray currents, fire protection and the growing use of mobile electronic technology.

In addition, the opportunity was taken to include new topics or to significantly reappraise topics previously covered that have undergone a shift in emphasis since the Fifth Edition. These include:

- Enclosed space entry.
- Human factors.
- Safety Management Systems (SMSs), including complementary tools and processes such as permits to work, risk assessment, Lock-out/Tag-out (LO/TO), Stop Work Authority (SWA) and their linkage to the underlying principles of the *International Safety Management (ISM) Code*.
- Marine terminal administration and the critical importance of the tanker/terminal interface.
- Alternative and emerging technologies.
- Bunkering operations, including the use of alternative fuels such as Liquefied Natural Gas (LNG).
- Cargo inspectors.
- Alignment with OCIMF's recently revised *Mooring Equipment Guidelines*.
- Maritime security and linkage to both the *International Ship and Port Facility Security (ISPS) Code* and industry's maritime security *Best Management Practices (BMP)*.

The Ship/Shore Safety and Bunkering Operations Checklists have also been completely revised to reflect changes in the understanding of the impact of human factors in their effective use. The importance of ensuring that individual and joint responsibilities for the tanker and the terminal are clearly communicated before arrival, as well as when alongside, is central to this objective.

The Sixth Edition of *ISGOTT* retains the four section format of:

Part 1 General Information
Part 2 Tanker Information
Part 3 Marine Terminal Information
Part 4 Ship/Shore (Tanker/Terminal) Interface

Care has been taken to ensure that where the guidance given in previous editions is still relevant and accurate, any amendments, changes or deletions have only enhanced the content and not diminished the ethos of ensuring the health, safety and environmental protection of those who use the guide.

The authors believe that *ISGOTT Sixth Edition* continues to provide the best technical guidance on oil tanker and terminal operations. All operators are urged to ensure that the recommendations in this guide are not only read and fully understood, but are also followed through their SMSs and procedures.

Purpose and Scope

The primary purpose of the *International Safety Guide for Oil Tankers and Terminals (ISGOTT)* is to provide operational advice to assist personnel directly involved in tanker and terminal operations. It makes recommendations for tanker and terminal personnel on the safe carriage and handling of crude oil and petroleum products on tankers and at terminals. It does not, however, provide a definitive description of how tanker and terminal operations are conducted.

To achieve its purpose *ISGOTT* provides guidance on, and examples of, certain aspects of tanker and terminal operations and how they may be managed. Effective management of risk demands SMSs, processes and controls and procedures that can quickly adapt to change. Therefore, the guidance given is, in many cases, intentionally non-prescriptive and alternative procedures may be adopted by operators in the management of their operations. These alternative procedures may exceed the recommendations contained in this guide and are strongly encouraged where they will further enhance the safety objective.

When adopting alternative procedures, operators should follow a risk-based management process that incorporates systems for identifying and assessing the risks and for demonstrating how they are safely managed. Guidance in the Sixth Edition is aimed at further assisting operators of tankers and marine terminals in these principles of safe management. For shipboard operations, this course of action must satisfy the requirements of the ISM Code.

In all cases, the advice given in *ISGOTT* is subject to any international, national or local regulations that may be applicable and is intended only to complement or strengthen those requirements. Companies responsible for the operation of tankers and terminals should ensure that they are aware of any such requirements and ensure full compliance.

It is recommended that a copy of *ISGOTT* is kept and used on board every tanker and in every marine terminal to provide advice on operational procedures and the shared responsibility for operations at the ship/shore interface.

Certain subjects are dealt with in greater detail in other publications issued by the IMO, ICS or OCIMF or by other maritime industry organisations. Where this is the case, an appropriate reference is made and a list of these publications is given in the bibliography.

It is not the purpose of the guide to make recommendations on design or construction of tankers. Information on these matters may be obtained from national authorities and from authorised bodies such as Classification Societies. Similarly, the guide does not attempt to deal with certain other safety related matters, e.g. navigation, helicopter operations and shipyard safety, although some aspects are inevitably touched upon.

It should also be noted that the scope of *ISGOTT* relates only to cargoes of crude oil and petroleum products that are carried in oil tankers, chemical tankers, gas carriers and combination carriers certified for the carriage of petroleum products. Therefore, it does not cover the carriage of chemicals or liquefied gases other than in the context of where they may be used on board oil tankers, e.g. LNG as a marine fuel. The carriage of chemicals and gases as cargo are the subject of other industry guides.

Industry guidance such as *ISGOTT* is based on the best knowledge and information available to the authors. Irrespective of this and the subject matter, or how strong and important the information provided, the industry is not in a position to mandate its own advice. For this reason, industry guidance in *ISGOTT* is characterised by the word 'should'. IMO regulations implemented by national administrations are legally enforceable and, therefore, when *ISGOTT* references such regulations or their implications the term used is 'must'.

Finally, the guide is not intended to encompass offshore facilities such as Floating Production Storage and Offloading Units (FPSOs) and Floating Storage Units (FSUs); operators of such units may, however, wish to consider the guidance given to the extent that good tanker practice is equally applicable to their operations.

Comments and suggestions for improvement are always welcome for possible inclusion in future editions. They may be addressed to any of the three sponsoring organisations as follows:

International Chamber of Shipping
38 St Mary Axe
London
EC3A 8BH
United Kingdom
web: www.ics-shipping.org

Oil Companies International Marine Forum
29 Queen Anne's Gate
London
SW1H 9BU
United Kingdom
web: www.ocimf.org

International Association of Ports and Harbors
7th Floor
South Tower New Pier Takeshiba
1-16-1 Kaigan
Minato-ku
Tokyo 105-0022
Japan
web: www.iaphworldports.org

CHAPTER 8

Alternative and Emerging Technologies

This chapter describes how alternative and emerging technologies can be assessed to make sure they do not affect safety on tankers and terminals. The due diligence process can be used in the tanker's SMS and safety manuals on the terminal. For more detail on alternative and emerging mooring technologies, see OCIMF's *Mooring Equipment Guidelines*.

8.1 Definition

Alternative technologies are technologies that have a documented track record in another sector but are not yet adopted in the tanker and terminal sector.

Emerging technologies are technologies that do not have a documented track record in any sector but could be developed in the future to improve the safety and the efficiency of the tanker and terminal sector.

In both cases, no known best practice would exist for the tanker and terminal sectors.

8.2 Examples

At the time of publication, the following alternative or emerging technologies exist:

- Marine Autonomous Surface Ships (MASS).
- Autonomous Underwater Vehicles (AUV).
- Marine mobile technology, e.g. intrinsically safe electronic tablets and telephones.
- Aerial drones.
- Robotic crawlers.
- Cold ironing.
- Methanol bunkering.
- Hydrogen fuel cell management.
- Electric cell propulsion power supply.

The list is not exhaustive. This guide does not endorse or oppose the listed technologies, but they may be considered for use following a structured due diligence and formal risk assessment process.

8.3 Due diligence process

8.3.1 Evaluation

Before considering the adoption of an alternative or emerging technology, a preliminary design review should be completed to evaluate the:

- General description and its equivalency to existing technologies.
- Functional description and its equivalency to existing technologies.
- Interface with existing technologies.
- Interface with existing systems and operational processes.
- Preliminary documentation, design drawings, general arrangements, product specifications and applicable codes and standards.
- Detailed formal safety and operational risk assessment plans, including assessments of human factors.
- Any additional design basis documentation.
- Consistency with other industry reference materials, e.g. the World Association for Waterborne Transport Infrastructure (PIANC) or the International Association of Classification Societies (IACS).

8.3.2 Impact

The tanker and terminal should complete an impact assessment before agreeing to use an alternative or emerging technology at the marine interface. This process should be documented and ensure that both parties have assessed and understood the risks of using the alternative or emerging technology.

If either the tanker or terminal is unable to complete the impact assessment, they should tell the other party what technology is being used and share any relevant documentation to support its use, e.g. the risk assessment and evaluation reports of design and product specifications.

If the alternative or emerging technology only affects the tanker or the terminal, the above exchange does not need to happen unless a general understanding would be useful.

8.3.3 Equivalency

Equivalency should be demonstrated through detailed data analysis of engineering or design studies, prototype and/or on-site testing and experience. Compare the data analysis of the alternative or emerging technology with the existing technology it is replacing or being used alongside.

Equivalency should show that the alternative or emerging technology is at least as good as the existing technology in delivering:

- The safety of tanker and terminal personnel.
- The assurance that the risks continue to be effectively managed.
- Suitable margins of safety that include the probability and consequence of system failure.
- Operational effectiveness and integrity.
- Compliance with applicable regulations, standards and recommended industry guidance and best practices.

8.3.4 Formal safety risk assessments

Formal, documented and detailed safety risk assessments should be carried out to understand the risks of using alternative or emerging technologies. It is recommended that personnel conducting these risk assessments:

- Are experienced in the methods of risk assessment being used.
- Have a detailed working knowledge of the alternative or emerging technology, the equivalent existing technology and industry best practices.

Classification Societies, marine consultants or other organisations may provide an independent formal safety risk assessment or guidance on how to effectively evaluate alternative and emerging technologies.

The IMO also provides guidance to administrations for approving alternatives and equivalents in MSC.1/Circ.1455 *Guidelines for the Approval of Alternatives and Equivalents as Provided for in Various IMO Instruments.*

Factors to consider in a formal safety risk assessment of an alternative or emerging technology include:

- Hazards associated with the alternative or emerging technology and/or its equivalency.
- Safeguards incorporated into the design of the alternative or emerging technology, including measures to ensure the safety of personnel.
- Human factors and any risk reducing benefits from adopting the alternative or emerging technology.
- Risk modelling to identify frequencies and potential consequences of hazards.
- Risks related to the local conditions and locally required operations.
- Issues that may require further detailed analysis and testing/evaluation.
- Issues that may require special attention with respect to operations, inspection and maintenance, including personnel, equipment and systems redundancy.
- How the alternative or emerging technology works under different environmental conditions, e.g. air temperature, marine spray or ice.

8.3.5 Stakeholder engagement

The number and type of stakeholders involved in evaluating an alternative or emerging technology will depend on its impact and the complexity of its implementation.

Stakeholder mapping is recommended for identifying stakeholders who are important to the evaluation and success of the alternative or emerging technologies.

GUIDANCE NOTES ON

QUALIFYING NEW TECHNOLOGIES

APRIL 2017

American Bureau of Shipping
Incorporated by Act of Legislature of
the State of New York 1862

ABS Plaza
16855 Northchase Drive
Houston, TX 77060 USA

Foreword

The marine and offshore industries regularly develop new technologies that have no service history in the proposed application or environment. Often, governing industry codes and regulations do not develop at the same pace as technology. These new technologies have little or no precedent and may be so different from existing designs that the requirements contained in class Rules may not be directly applicable.

These Guidance Notes describe the ABS approach for qualification of new technologies to confirm their ability to perform intended functions in accordance with defined performance requirements. This document also provides details regarding the required submittals and the key interaction points with ABS during the new technology development to benefit from ABS involvement as a trusted advisor.

A systems engineering approach to qualification is introduced in this document that allows for systematic and consistent evaluation of new technologies as they mature from a concept through confirmation of operational integrity in their intended applications. The approach is divided into a five stage process that is aligned with the typical product development phases of a new technology:

- Feasibility Stage
- Concept Verification Stage
- Prototype Validation Stage
- System Integration Stage
- Operational Stage

Completion of qualification activities within each stage of the new technology qualification process results in a Statement of Maturity issued to the client attesting to the maturity level of the new technology. Upon completion of the Prototype Validation Stage, the new technology may be “Type Approved” under the ABS Type Approval Program to limit repeated evaluation of identical designs for eligible products. During the Prototype Validation Stage, if all the engineering evaluations have been completed, a Product Design Assessment (PDA) can be issued prior to further consideration for ABS Type Approval.

The integration of the new technology qualification process with the Novel Concept Class Approval process (as presented within the ABS *Guidance Notes on Review and Approval of Novel Concepts*) provides end users of the qualified technologies with the added benefit that the transition from new technology qualification to Class Approval will be seamless. It provides regulatory agencies with the confidence that all hazards associated with the introduction of the new technology to the market has been systematically identified and mitigated. It is to be noted that when applying these Guidance Notes for certification or classification purposes in conjunction with Novel Concept Class Approval process, the primary driver for classification acceptance will be safety even though there may be additional functional requirements (e.g., reliability) defined by the client.

These Guidance Notes become effective on the first day of the month of publication.

Users are advised to check periodically on the ABS website www.eagle.org to verify that this version of these Guidance Notes is the most current.

We welcome your feedback. Comments or suggestions can be sent electronically by email to rsd@eagle.org.

Terms of Use

GUIDANCE NOTES ON

QUALIFYING NEW TECHNOLOGIES

CONTENTS

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SECTION 1 Introduction

1 Overview

These Guidance Notes describe the ABS approach for qualification of new technologies to confirm their ability to perform intended functions in accordance with defined performance requirements. They also provide details of the required submittals, the ABS review process and the key interaction points with ABS during the new technology development.

This document introduces a systems engineering approach to qualification that allows for systematic and consistent evaluation of new technologies as it matures from a concept through confirmation of operational integrity in its intended application. The approach is divided into a multi-stage process that is aligned with the typical product development phases of a new technology. The qualification activities within each stage employ risk assessments and engineering evaluations that build upon each other in order to determine if the new technology provides acceptable levels of safety in line with current offshore and marine industry practice. The qualification efforts by all stakeholders including the vendor, system integrator and end-user at each stage are recognized and captured within a new technology qualification plan (NTQP). Completion of qualification activities as identified within each stage of the NTQP results in a Statement of Maturity being issued by ABS attesting to the maturity level of the new technology.

The process is also compatible with approaches based on technology readiness levels (TRLs), (e.g. API RP 17N/Q, ISO 16290/NASA, and US DoD); and can be tailored to projects that require the use of multiple pathways to qualification. The comparison of ABS Qualification Stages with industry TRLs can be found in Appendix 2.

It is to be noted that when applying these Guidance Notes for certification or classification purposes in conjunction with Novel Concept Class Approval process, the primary driver for classification acceptance will be safety even though there may be additional functional requirements (e.g., reliability) defined by the client.

3 Background

The marine and offshore industries regularly develop new technologies that have no service history in the proposed application or environment. Often, governing industry codes and regulations do not develop at the same pace. These new technologies have little or no precedent and may be so different from existing designs that the requirements contained in class Rules may not be directly applicable.

Marine vessels and offshore units which contain new technological features or designs that are not currently governed by Rules, Guides and existing industry standards may still be qualified and/or approved by ABS through the process described in these Guidance Notes. This qualification is on the basis that the Rules, Guides, and existing industry standards, insofar as applicable, have been complied with, and that special consideration through appropriate risk assessments and engineering evaluations has been given to the new features through the application of these Guidance Notes.

These Guidance Notes are structured to provide a general procedure for vendors/system integrators/end-users to guide them through the process of obtaining Statements of Maturity attesting to the maturity level of new technologies. The process can be applied to technologies seeking qualification independent of class approval or installation on ABS classed assets.

The integration of the new technology qualification process and the Novel Concept Class Approval process provides end users of the qualified technologies with the added benefit that the transition from new technology qualification to Class Approval will be seamless. It provides regulatory agencies with the confidence that hazards associated with the introduction of the new technology has been systematically identified and mitigated.

5 Application

These Guidance Notes are in general applicable to all new technologies for offshore units and marine vessels that do not follow typical Rules, Guides, or industry codes or standards. This document provides guidance to parties seeking recognition for the maturity level of a proposed new technology.

A new technology for the purpose of these Guidance Notes is defined as any design (material, component, equipment or system), process or procedure which does not have prior in-service experience, and/or any classification rules, statutory regulations or industry standards that are directly applicable. It is possible to categorize the type of "novelty" in one of four categories:

i) Existing design/process/procedures challenging the present boundaries/envelope of current offshore or marine applications

ii) Existing design/process/procedures in new or novel applications

iii) New or novel design/process/procedures in existing applications.

iv) New or novel design/process/procedures in new or novel applications

An asset such as a marine vessel or an offshore unit becomes a novel concept if the incorporation of any new technology(ies) appreciably alters its service scope, functional capability, and/or risk profile. Novel concepts are typically presented to ABS for review and class approval following the process in the ABS *Guidance Notes on Review and Approval of Novel Concepts (Novel Concept Guidance Notes).*

The New Technology Qualification (NTQ) process could be applicable in the following cases:

i) To qualify new technology that may need to be classed or certified at a later date

ii) To simultaneously qualify new technology identified while seeking class approval for a novel concept

iii) To qualify a new technology independent of the need to be classed or certified

If the proposed new technology is intended for incorporation on an asset to be classed by ABS, then it is recommended that the new technology complete up to and including the System Integration Stage of the New Technology Qualification (NTQ) process. In other cases, the level of maturity to which the new technology may be qualified depends on the client's request. New technology qualification could be requested from ABS at any level of indenture as desired such as component, sub-system or system level.

The process is designed to accommodate cases where multiple vendors, system integrators, and/or end-users need to work together to qualify a combination of new technologies. In such cases, it is important for the teams to work together to integrate technologies as early as possible in order to optimize the process. Even though these Guidance Notes are primarily intended for the qualification of new technologies, the approach could also be applied to qualify existing technologies.

7 New Technology Qualification Process

The NTQ process confirms the ability of a new technology to perform its intended functions in accordance with defined performance requirements. The process starts with a comprehensive description of the technology to be qualified, followed by a screening of the technology to reveal the new or novel features that the qualification should focus on.

The process is divided into five sequential stages that progressively qualify the technology from feasible to operational stages as requested. The five qualification stages are:

i) Feasibility Stage

ii) Concept Verification Stage

iii) Prototype Validation Stage

iv) System Integration Stage

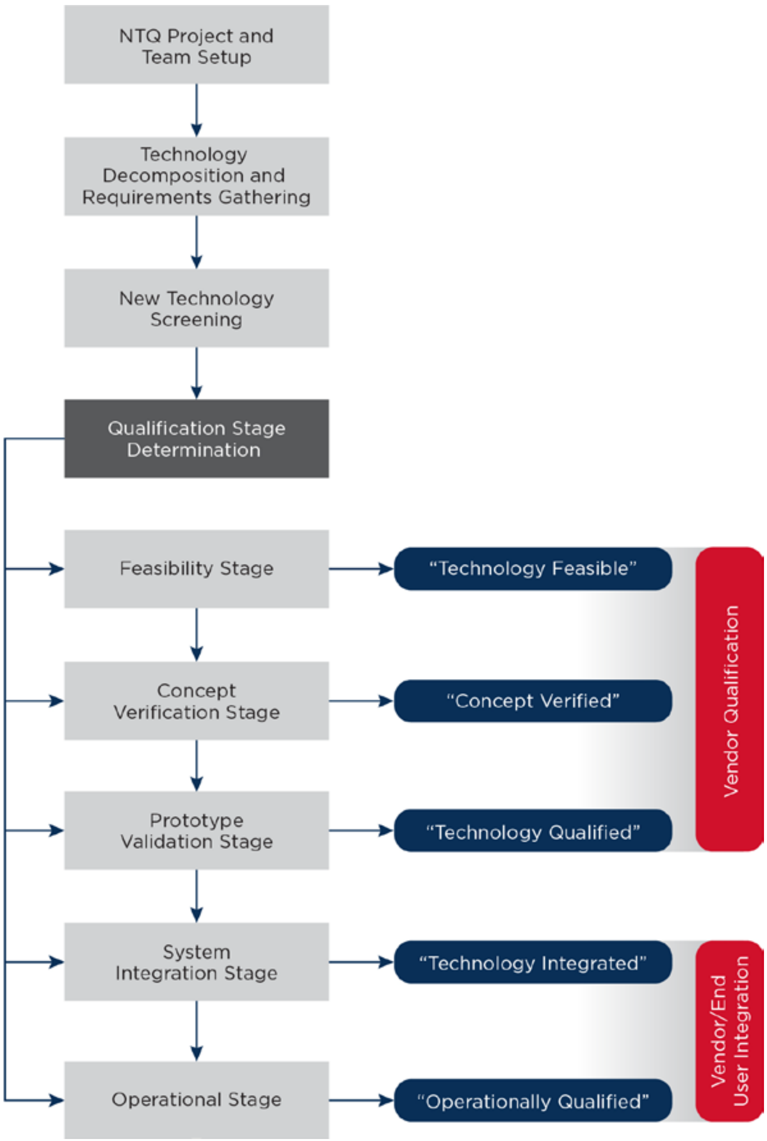
v) Operational Stage

Qualification activities outlined in the New Technology Qualification Plan (NTQP), are to be performed within each stage and should be defined at the end of the previous stage as agreed between the client and ABS. The qualification activities are based on the information available depending on the maturity level and based on the findings and knowledge gained in the previous stages completed. Typically, there are two main sets of activities within each stage, namely, engineering evaluations and risk assessments.

Upon completion of each of the five stages, a Statement of Maturity will be issued to the vendor(s) and the technology can progress to the next stage of maturity. It is envisioned that some vendors may have developed technologies to a level beyond the Feasibility Stage prior to contacting ABS for this qualification service. In such cases, ABS would perform an assessment of the current stage of technology development and endorse the technology with the applicable Statement of Maturity based on this assessment. The technology qualification can then proceed starting at that stage and continuing to the subsequent stages. Additionally, the new technology qualification process can be stopped at any stage, and restarted at an agreed upon time.

Section 1, Figure 1 provides a basic overview of the process along with the Statements of Maturity issued. Further guidance on each topic and deliverables that are to be submitted to ABS for review can be found in later Sections.

FIGURE 1
New Technology Qualification Process



9 ABS Type Approval Program

New technologies that have completed the Prototype Validation Stage of the NTQ process or have been "Technology Qualified", and can be consistently manufactured to the same design and specification may be "Type Approved" under the ABS Type Approval Program. During the Prototype Validation Stage, if all the engineering evaluations have been completed, a Product Design Assessment (PDA) can be issued prior to further consideration for ABS Type Approval. The ABS Type Approval Program is a voluntary option for the demonstration of compliance of a system or product with the defined performance requirements as derived from Rules, Guides, or other recognized standards. It may be applied at the request of the vendor or manufacturer. The suitability of the ABS Type Approval Program for the proposed new technology will be determined on a case-by-case basis.

Specific requirements and details regarding the ABS Type Approval Program can be found in 1-1-4/7.7 and Appendix 1-1-A3 of the ABS *Rules for Conditions of Classification (Part 1).*

11 Definitions

As Low As Reasonably Practicable (ALARP). Refers to a level of risk that is neither negligibly low nor intolerably high, for which further investment of resources for risk reduction is not justifiable. Risk should be reduced to ALARP level considering the cost effectiveness of the risk control options.

Approval. Confirmation that the plans, reports or documents submitted to ABS have been reviewed for compliance with one or more of the required Rules, Guides, standards or other criteria acceptable to ABS.

Availability. Ability of an item to be in a state to perform a required function under given conditions at a given instant of time or over a given time interval, assuming that the required external resources are provided (ISO 14224).

Boundary. Interface between an item and its surroundings (ISO 14224).

Client. The vendor, OEM, manufacturer, asset owner/operator of the new technology or novel concept, representing any party or parties that have a stake or interest in the design or third party groups working under or for these entities.

Consequence. The measure of the outcome of an event occurrence in terms of people affected, property damaged, outage time, dollars lost or any other chosen parameter usually expressed in terms of consequence per event or consequence amount per unit of time, typically per year.

Controls. The measures taken to prevent hazards from causing undesirable events. Controls can be physical (e.g., safety shutdowns, redundant controls, added conservatism in design, etc.), procedural (e.g., operating procedures, routine inspection requirements, etc.) and can also address human factors (employee selection, training, supervision).

Critical Assumption. An assumption that if found not true will change the conclusions of the study that used such assumption.

Engineering Evaluations. Various engineering analysis tools and testing that may be used to support new technology qualification activities. Typical examples include but not limited to the following: Finite Element Analysis (FEA), Computational Fluid Dynamics (CFD), Functional and Performance Testing, Model Testing, System Integration Testing, etc.

Failure. The loss of the ability to perform the intended function.

Failure Causes. Circumstances associated with design, manufacture, installation, use and maintenance that have led to a failure (ISO 14224).

Failure Mechanism. A physical or chemical process resulting in a form of damage which will ultimately lead to failure.

Failure Mode. The specific manner of failure that the failure mechanism produces.

Functional Specification. Document that describes the features, characteristics, process conditions, boundaries and exclusions defining the performance and use requirements of the product, process or service (ISO 13880).

Frequency. The occurrence of a potential event per unit of time, typically expressed as events per year.

Global Effects. Total effect an identified failure has on the operation, function or status of the installation or vessel and end effects on safety and the environment.

Hazards. Conditions that exist which may potentially lead to an undesirable event.

Indenture Level. The level of subdivision of an item from the point of view of maintenance action (ISO 14224).

Item. Any part, component, device, subsystem, functional unit, equipment or system that can be individually considered (ISO 14224).

Local Effects. Impacts that an identified failure mode has on the operation or function of the item under consideration or adjacent systems.

Maintainability. Ability of an item under given conditions of use, to be retained in, or restored to, a state in which it can perform a required function, when maintenance is performed under given conditions and using stated procedures and resources (ISO 14224).

Manufacturing Assessment (MA). An inspection of the product during manufacture, an assessment of the quality control system and manufacturing processes that must be satisfactorily completed if the manufacturer wants a product to be labeled "Type Approved" under the ABS Type Approval Program.

Manufacturing Plan. Document setting out the specific manufacturing practices, technical resources and sequences of activities relevant to the production of a particular product including any specified acceptance criteria at each stage (ISO 13880).

Product Design Assessment (PDA). Technical evaluation of a product for potential use on ABS-classed assets. The process involves ABS Engineers verifying product compliance with manufacturers' specifications, applicable ABS Rules and national or international standards.

Quality Assurance and Quality Control. Typical quality plans and related processes for controlling quality during production.

Qualification. The process of confirming, by examination and provision of evidence, that equipment meets specified requirements for the intended use (API RP 17N).

Qualification Activities. Usually in the form of risk assessments, engineering evaluations, and testing that is required to be performed in order to mature the new technology to the next stage.

Qualification Plan. A document containing the qualification activities listed to mature the new technology to the next qualification stage. This is submitted as a New Technology Qualification Plan (NTQP) report.

Redundancy. Existence of more than one means for performing a required function of an item (ISO 14224).

Reliability. Ability of an item to perform a required function under given conditions for a given time interval (ISO 14224).

Risk. The product of the frequency with which an event is anticipated to occur and the consequence of the event's outcome.

Risk Profile. Description of any set of risks (ISO 31000).

Technical Specification. Document that defines technical requirements to be fulfilled by the product, process or service in order to comply with the functional specification (ISO 13880).

Type Approval. A voluntary ABS Program for product certification that is used to demonstrate a product manufacturer's conformance to the Rules or other recognized standards. The Product Design Assessment (PDA) and Manufacturing Assessment (MA) together result in a Type Approval or a "Type Approved" product.

Validation. The process of evaluating a production unit (or full scale prototype) to determine whether it meets the expectations of the customer and other stakeholders as shown through performance of a test, analysis, inspection, or demonstration.

Verification. The process of evaluating a system to determine whether the product of a given development stage satisfy the approved requirements and can be performed at different stages in the product life cycle by test, analysis, demonstration, or inspection.

13 Abbreviations

ALARP	As Low As Reasonably Practicable
API	American Petroleum Institute Recommended Practice
CFD	Computational Fluid Dynamics
FEA	Finite Element Analysis
FMECA	Failure Mode Effects and Criticality Analysis
FTA	Fault Tree Analysis
HAZOP	Hazard and Operability
HAZID	Hazard Identification
HFE	Human Factors Engineering
ITP	Inspection Test Plan
MA	Manufacturing Assessment
MTBF	Mean Time Between Failure
NTQ	New Technology Qualification
NTQP	New Technology Qualification Plan
PDA	Product Design Assessment
PFD	Process Flow Diagram
P&ID	Piping and Instrumentation Diagram
PPE	Personal Protective Equipment
QA	Quality Assurance
QC	Quality Control
RAM	Reliability, Availability and Maintainability
RBD	Reliability Block Diagram
SRDD	Systems Requirements and Description Document
SIT	Systems Integration Test
US DoD	United States Department of Defense

SECTION 2 Getting Started

1 New Technology Qualification Project and Team Setup

Once the client (vendor/system integrator/end-user) requests qualification of a technology using these Guidance Notes, a project kick-off meeting is scheduled. At this meeting, the client presents to ABS a brief overview of their proposed technology along with their expectations, any ongoing qualification activities (if initiated) and project timelines. ABS will advise the client if new technology qualification is the most appropriate path for proceeding and recommend next steps.

The kick-off meeting is followed by the establishment of a new technology qualification team. An important factor for a successful technology qualification is the composition of the qualification team. The qualification process involves the interaction of two teams: the vendor or client team (design team) and the ABS-designated review team.

For each NTQ project, depending on the complexity of the proposed new technology, ABS may establish a special multidisciplinary review team comprised of ABS staff members. The composition of the team will depend on the technical areas involved in the project as well as the physical location of the client's engineering and testing facilities. This will help the client benefit from technical review and comment from our subject matter experts throughout the qualification process. One of the members will be the designated NTQ project lead to act at as the client's main point of contact throughout the NTQ process. All ABS team members will be covered under the confidentiality/non-disclosure agreement that is typically signed between ABS and clients for this type of qualification services.

It is encouraged whenever possible to include ABS, system integrators and end users of the new technology early in the qualification process. This will facilitate the identification and alignment of requirements early in the design process avoiding costly design modifications later. If applicable, input from regulatory agencies (including flag Administration) will also help align the qualification activities with requirements or other expectations.

3 New Technology Decomposition and Requirements Gathering

3.1 Introduction

The NTQ process follows a systems engineering approach to qualifying new technology. This approach focuses on the following elements:

- Defining goals of the new technology
- Identifying the functional requirements to meet the goals
- Identifying the performance requirements for the functional requirements
- Performing qualification activities to verify and validate the performance requirements

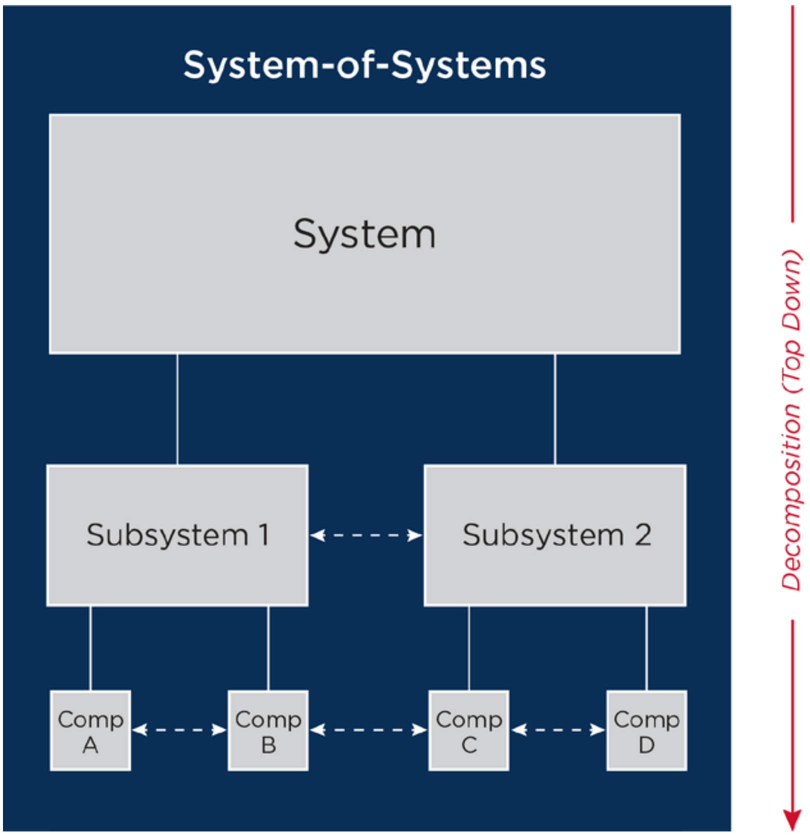
The qualification process starts with a top-down system decomposition, wherein the system is divided into subsystems, which are further broken down into components. This decomposition process is used in order to achieve the following:

- Mapping functional requirements of the system to item(s) (e.g., subsystems or components) identifying ownership of a specific functional requirement,
- Mapping functional requirements to specific performance requirements,
- Confirming that all defined functional requirements can be addressed by configurable items,
- Identifying new technology items prior to determining if qualification is needed and what interactions between items need to be considered.

Depending on the type of item for which the client is seeking qualification, the NTQ process can be tailored. This is applied by considering the different categories of new technology as defined in Subsection 1/5 and understanding what exactly has changed to focus qualification efforts.

The maximum maturity level of the system is based on the individual qualification of each item(s). For example, the overall maturity level of the system is equal or lower than that of the subsystems, which are equal or lower than that of the individual components. The decomposition, system hierarchy and interactions between all items are depicted in Section 2, Figure 1.

FIGURE 1
New Technology System Hierarchy



The item for which new technology qualification is desired could be at any level of indenture within the system hierarchy. System-of-Systems (SoS) refers to the larger system with which integration of the new technology could occur. This SoS could be another system or an asset such as a marine vessel or an offshore unit. The asset becomes a novel concept if the incorporation of any new technology(ies) appreciably alters its service scope, functional capability, and/or risk profile.

3.3 New Technology System Requirements and Description Document

Properly defining a new technology is a critical aspect of NTQ. For this purpose, a system requirements and description document (SRDD) should be developed for the new technology and maintained throughout the NTQ process. This document defines and sets the baseline requirements for the new technology and may be derived from functional and technical specifications. The requirements will be defined for each level within the system hierarchy as applicable. As the design matures through development and more knowledge is gained through qualification, these requirements may be subject to change. The SRDD will need to be updated accordingly.

3.3.1 Defining System Requirements

3.3.1(a) Goals. The goals defined for the new technology should identify the high-level scope, objectives, or requirements that the new technology needs to meet. Goals may be derived from client's needs, mission, measures of effectiveness, environmental or application constraints, program/policy decisions and/or requirements derived from tailored specifications or standards.

3.3.1(b) Functional Requirements. Functional requirements define each function that the system is required to perform. The functional requirements should be mapped to specific items that will perform the function and typically includes a description of the function to be performed, the environment within which the function should be performed, the conditions under which the system should start the function and the conditions under which the system should terminate the function.

3.3.1(c) Performance Requirements. The performance requirements define how well each functional requirement should be accomplished, and the set of performance metrics including identification of critical performance parameters. The performance requirements can be defined qualitatively at early design stages and progressively more quantitatively during subsequent stages of technology maturation. In case where performance requirements are not defined because of the novelty of the technology, the requirements should be extrapolated from existing Rules, Guides, and/or other industry standards. Any relevant requirements from regulatory agencies or Flag Administration should be also considered. The performance criteria is the acceptance criteria against which the results of each qualification activity is evaluated.

The requirements should be defined according to NATO AVT-092 "Qualification by Analysis" and/or ISO 13879 "Petroleum and natural gas industries – Content and drafting of a functional specification". The aspects to consider for inclusion while defining functional requirements and related performance requirements may vary depending on the new technology to be qualified but typical considerations include:

3.3.1(d) Design Conditions. The system design conditions describe all applicable loading requirements under the environmental and operating conditions. This should include, but not be limited to, the natural environment (e.g., temperature and chemical exposure), the induced environment (e.g., vibration and noise), electromagnetic signal environment, and threats. Typical loading and design conditions to be considered include, but are not limited to, the following:

- Pressure and temperature induced loads and fluctuations
- Static and dynamic loads
- Fatigue and fracture effects
- Wear and vibration effects
- Material degradation and associated loss from damage mechanisms
- Accidental loads (as applicable)

3.3.1(e) System Interface Requirements. The system interface requirements define all internal and external physical and functional interfaces (e.g., mechanical, electrical, etc.) relevant to the new technology. Interfaces among system elements should also include interfaces with the human element. The system interface definition confirms that various elements of the system can functionally and physically interact with each other and with all external systems they connect to or communicate with. A graphic description of the interfaces can be used when appropriate for clarity.

3.3.1(f) Human System Integration Requirements. Human factors play an important role for the system to work safely and effectively in achieving required functions and goals, and should be considered throughout the design life of the new technology. Human factors requirements (ergonomics) define the characteristics of human system interaction in terms of usability, safety, human reliability, performance, effectiveness, efficiency, maintainability, and health. It is important that human factors be considered during early design stages.

Human Factors Engineering (HFE) is a specialized engineering discipline that integrates human behavioral and physical capabilities and limitations with traditional engineering disciplines to produce a human-system interaction that maximizes the best of both, allowing both the human and system to work together in achieving functional and performance requirements.

The focus of HFE is the design of the human-system interface. This includes interfaces between personnel and the hardware, software, and physical environments associated with systems. It also involves the interfaces between personnel, individual tasks, and the overall work system (e.g., its structure, management, policies, and procedures). A good starting point is defining usability requirements which identify user needs and expectations. Usability requirements define the appropriate allocation of functions between users and the technology as well as the measurable effectiveness, efficiency, and satisfaction criteria in specific contexts of use.

During the design process, specific areas, stations, or equipment arrangement that would require concentrated human engineering attention should be defined. Any special requirements, such as constraints on allocation of functions to personnel and communications and personnel/equipment interactions, should be specified. Successful application of HFE depends on a proper process of conducting the appropriate activities in the various stages of the development lifecycle of the system.

Further guidance on Human Factors Engineering can be found in the following references:

- ABS *Guide for Ergonomic Notations*
- ABS *Guidance Notes on the Implementation of Human Factors Engineering into the Design of Offshore Installations*
- ABS *Guidance Notes on the Application of Ergonomics to Marine Systems*
- ABS *Guidance Notes on Ergonomic Design of Navigation Bridges*
- *Standard Human Engineering Program Requirements for Ships and Marine Systems, Equipment and Facilities, Standard 1337. American Society of Testing and Materials (ASTM) (2010)*
- *Common Requirements, Architectural Components & Equipment (C-CR-002). Norwegian Oil Industry Association and the Federation of Norwegian Engineering Industries (NORSOK). (1996)*
- *Working Environment (S-002). Norwegian Oil Industry Association and the Federation of Norwegian Engineering Industries (NORSOK). (2004)*

3.3.1(g) Maintainability. Specify the quantitative maintainability requirements that apply to maintenance in the planned maintenance and support environment. Examples are as follows (ISO 29148):

- Time (e.g., mean and maximum downtime, reaction time, turnaround time, mean and maximum times to repair, mean time between maintenance actions)
- Rate (e.g., maintenance staff hours per specific maintenance action, operational ready rate, maintenance time per operating hour, frequency of preventative maintenance)
- Maintenance complexity (e.g., number of people and skill levels, variety of support equipment, removing/replacing/repairing components)
- Maintenance action indices (e.g., maintenance costs per operating hour, staff hours per overhaul)
- Accessibility to components within systems and to parts within components

3.3.1(h) Reliability. Reliability describes the ability of a system or component to function under stated conditions for a specified period of time. Reliability requirements determine the robustness, consequences of, and redundancy of the system. Reliability requirements are best stated as quantitative probability statements that are measurable by test or analysis, such as the mean time between failures (MTBF) and the maximum acceptable probability of the failure during a given time period.

3.3.1(i) Safety and Environment. Safety and environmental requirements applicable to eliminating or minimizing hazards related to people, environment, and asset.

3.3.1(j) System Life Cycle Sustainment. The system life cycle sustainment requirements include activities that relate to sustaining the quality or integrity of the system. Typical requirements include, but are not limited to, support, sparing, sourcing and supply, provisioning, technical documentation, personnel support training for all modes of operation (e.g., installation, hook-up, commissioning, and decommissioning) throughout the life cycle of the system. These requirements should be updated as needed in order to sustain performance.

3.3.1(k) Data Management and System Security. For data-intensive systems, the management of information should be defined. The information management requirements should define the information the system receives, stores, generates and exports as well as the backup of the information.

System security requirements define both the surrounding environment (i.e., location) of the system and the operational security requirements. For example, to protect the system from accidental or malicious access, use, or destruction, some protection methods (e.g., access limitations, use of passwords, or the restriction of communications between some areas of the system) can be used. For control systems that govern multiple critical aspects of the assets, insights should be provided for operations, maintenance and support of cyber-enabled systems, to improve security in those systems.

The ABS CyberSafety™ program addresses cyber-enabled systems protection in an extended set of engineering processes that emphasizes human and systems safety. For further guidance on this program refer to the following documents:

- ABS *Guidance Notes on Application of Cybersecurity Principles to Marine and Offshore Operations – ABS CyberSafety™ Volume 1*
- ABS *Guide for Cybersecurity Implementation for the Marine and Offshore Operations – ABS CyberSafety™ Volume 2*
- ABS *Guidance Notes on Data Integrity for Marine and Offshore Operations – ABS CyberSafety™ Volume 3*
- ABS *Guide for Software Systems Verification – ABS CyberSafety™ Volume 4*
- ABS *Guidance Notes on Software Provider Conformity Program – ABS CyberSafety™ Volume 5*

3.3.2 System Description

The SRDD is also to include a detailed technology description. This involves additional documentation that could help provide evidence or demonstrate the ability of the technology to meet defined system requirements. The description of the technology typically includes the following:

i) Equipment list

ii) Comparison with existing similar technologies

iii) Lessons learned from similar technologies

iv) Possible applicable standards, codes, or industry practices *v)* Relevant engineering documents as applicable:

- Piping and Instrumentation Diagrams (P&IDs)
- Heat and material balances
- Block diagrams
- Design schematics
- General arrangements
- Material specifications including material properties
- Design analysis methodology and related reports
- Installation analysis
- Test reports

vi) Control and safety system details

vii) Operational, maintenance, and inspection strategies

viii) New or unproven manufacturing, assembly, transit, storage, installation, hook-up, testing, commissioning, and decommissioning details

ix) Quality, health, safety, and environmental philosophies

The SRDD needs to be submitted for ABS review. The SRDD is not intended to be a single consolidated document but a design review package that compiles the relevant documents.

It is recognized that the requirements definition and the supporting description documentation is developed throughout the NTQ process. The submittal only needs to include the information available based on the design maturity of the new technology.

5 New Technology Screening

Once the technology has been described, a systematic screening process is needed in order to identify the new or novel elements, characteristics, or environment for which qualification is needed. The decomposed system should be reviewed to identify which of those items are considered new technology, as defined in Subsection 1/5, and which ones are not. The level of effort involved in qualification increases from categories *i)* through *iv)*. Items that are not considered new technology could follow the conventional ABS certification process.

For new technology items, it is useful to identify whether similar technology exists and whether relevant Rules, Guides, and/or standards apply wholly or partially for this technology. Identifying the new technology items provides a basis for reducing the qualification scope to only those items that need to be addressed through the NTQ process. The vendors could perform the screening process independently or in a workshop setting with ABS, which will help support/guide the process. Section 2, Table 1 below, is a sample table that can be used for a systematic screening.

TABLE 1
Systematic Screening Table

Item	*Description*	*Similar Technology Exists?*	*Relevant Rules, Guides, or Industry Standards for This or Similar Technology?*	*New Technology (Yes/No)*	*New Technology Category (i, ii, iii, iv)*	*Notes*
1		Technology 1, Technology 2…	Standard 1 (partially) Standard 2 (No)…	Yes	*i*	
2		No	Standard 1 (partially) Standard 2 (partially)…	Yes	*iii*	
3		This technology exists	N/A	No	N/A	

Columns:

Description: Description of elements of the new technology item(s) (e.g., subsystems)

Similar Technology Exists?: Identify whether similar technologies exist, for example, technologies in other industries (e.g., onshore, aerospace, etc.). If existing technology exists, list them in this column.

Relevant Standards for This or Similar Technology: List of any standards applicable to the new technology with short explanation about applicability.

New Technology (Yes/No): Decide which technologies are new and which are not.

New Technology Category: As defined in Subsection 1/5:

i) Existing technology challenging current boundary/envelope

ii) Existing technology in new applications

iii) New technology in existing applications

iv) New technology in new applications

Notes: Other information or justification relevant to the screening process (e.g., conditions for applicability of standards, recommendations for qualification, etc.).

The systematic screening results and supporting information is to be submitted for ABS review.

7 New Technology Stage Determination

Based on the results from the new technology screening process and review of the SRDD, ABS and the client will agree on a maturity level determination. An appropriate qualification stage will be assigned to proceed, with qualification activities. A detailed questionnaire for determining the technology maturity level and qualification stage can be found in Appendix 3.

A more mature design could result in the ability to start at a later qualification stage, thus minimizing the level of effort and time it takes to complete qualification of the new technology. Once credit has been given to the design maturity and the appropriate qualification stage is determined, the client can proceed through the qualification process outlined in the following Sections:

- Feasibility Stage (Section 3)
- Concept Verification Stage (Section 4)
- Prototype Validation Stage (Section 5)
- System Integration Stage (Section 6)
- Operational Stage (Section7)

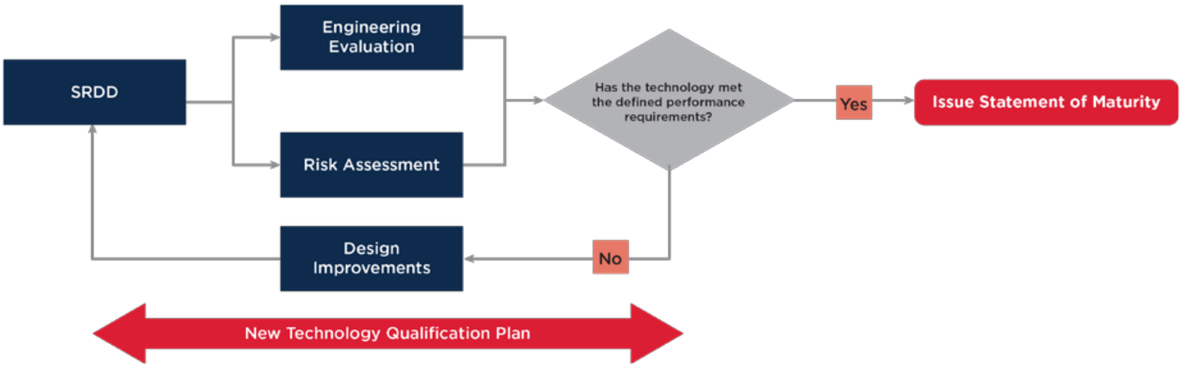
9 New Technology Qualification Plan and Activities

The New Technology Qualification Plan (NTQP) defines a roadmap for progressing the new technology through the appropriate qualification stages. The objective of the NTQP is to provide a summary of qualification activities that need to be performed at each stage in order to demonstrate the ability of the new technology to meet the requirements specified in the SRDD.

The initial NTQP should be developed based on the findings in the screening process in Subsection 2/5. The NTQP for each subsequent stage is updated based on the findings from the previous stage activities and discussions between the client and ABS. A NTQP template is provided in Appendix 4.

Qualification within each stage is comprised of a set of iterative activities that include engineering evaluations and risk assessments to verify new technology design. Results of these activities could lead to design improvements or modifications to the requirements specified in the SRDD. All design improvements and/or modifications should be documented in the NTQP with necessary technical justification. Section 2, Figure 2 summarizes the iterative NTQP activities.

FIGURE 2
New Technology Qualification Stage Iterative Process



9.1 Risk Assessment Requirements

As stated in Subsection 2/9, a risk assessment is to be prepared and submitted to ABS for review.

For a new technology requesting qualification through the NTQ process, a risk assessment is to be performed/updated at each stage as applicable. The risk assessment within the NTQ process will vary from qualitative to quantitative depending on the maturity level and information available at that stage. The primary objective of the risk assessment is to identify technical risks and uncertainties associated with the proposed design and document all foreseeable hazards, their causes, consequences, and potential risk control measures considering the new technology in its proposed application and operating environment. All possible interfaces, and known integrations are to be evaluated as part of this assessment.

All risk assessments performed must consider the following areas:

i) Personnel safety

ii) Asset protection

iii) Environmental protection

It is recommended that the risk assessment be carried out by a multidisciplinary team that includes the design team (vendor) and the end-user. ABS' participation in the risk assessment is also recommended. Appendix 2 of the ABS *Guide for Risk Evaluations for the Classification of Marine-Related Facilities* provides an overview of how to assemble an appropriate risk assessment team.

Prior to performing the risk assessment, a risk assessment plan should be prepared and submitted to ABS for review. The risk assessment plan should include the following information:

i) Scope of the Assessment

a) Description of the proposed new technology including physical and operational boundaries

b) Intended service application of the new technology

ii) Assessment Team

a) Subject matter experts/participants/risk analysts, including their background and areas of expertise

iii) Assessment Preparation

a) All available new technology information (e.g., design basis, drawings, procedures, etc.),

b) Proposed risk assessment method (e.g., FMECA)

c) Proposed risk assessment criteria for evaluation (e.g., risk matrix)

After the risk assessment has been completed, a report that includes the following information should be submitted to ABS for review:

i) Scope

a) Description of the proposed new technology including physical and operational boundaries

b) Intended service application of the new technology

ii) Risk Assumptions and Data References

iii) Supporting Engineering Documents

a) Technical drawings

iv) Risk Assessment Worksheets (Hazard Register) that

a) Identifies hazards associated with the new technology in its current boundary conditions (application and operating environment),

b) Identifies scenarios associated with each identified hazard,

c) Identifies causes of the hazardous scenario,

d) Identifies consequences of the hazardous scenario,

e) Identifies existing risk control measures for each hazardous scenario,

f) Estimates the likelihood (frequency) and the severity of the consequence,

g) Evaluates the risk of the hazardous scenario by measuring it against the acceptable risk criteria agreed upon by the analysis team,

h) Identifies and evaluates the need for any recommendations to lower the risk to acceptable levels (design improvements through risk control measures)

v) Conclusions and Recommendations

a) Action items and/or recommendations

Further guidance on developing basic and detailed risk assessment plans can be found in Section 5 and Section 6, respectively of the ABS *Guide for Risk Evaluations for the Classification of Marine-Related Facilities.*

It is recognized that each new technology may be unique in terms of design, operating environment, and application, therefore it is difficult to provide precise guidance on which risk assessment techniques should be used in a given situation. Therefore the selection of risk assessment methodology should be considered on a case-by-case basis and discussed with ABS prior to performing a risk assessment. Some typical recommended risk assessment techniques and their common uses can be found in Section 2, Table 2.

TABLE 2
Recommended Risk Assessment Techniques

Type of Study	*Description*	*Common Uses*
HAZID	A method to rapidly identify hazards, assess potential consequences, and evaluate existing safeguards of the system. Methods draw upon a highly experienced multi-disciplinary team using a structured brainstorming technique to assess applicability of potential hazards.	• Used for all types of systems and processes.
FHA	A functional hazard assessment (FHA) is used to identify and assess the functional failures of a system or subsystem.	• Used for all types of systems and processes.
FMEA (Failure Mode and Effects Analysis)	An FMEA is a reasoning approach best suited to reviews of mechanical and electrical hardware systems. The FMEA technique (1) considers how the failure modes of each system component can result in system performance problems and (2) makes sure the proper safeguards are in place. A quantitative version of FMEA is known as failure modes, effects and criticality analysis (FMECA).	• A design FMEA/FMECA can be used for reviews of mechanical and electrical systems (e.g., fire suppression systems, vessel steering and propulsion systems) to identify design related failures. • A process FMEA is often used to identify failures while performing steps within a given process or procedure (e.g., manufacturing, assembly).
Hazard and Operability (HAZOP) analysis	The HAZOP analysis technique uses special guide words for (1) suggesting departures from design intents for sections of systems and (2) making sure that the proper safeguards are in place to help prevent system performance problems.	• Used for finding safety hazards and operability problems in continuous process systems, especially fluid and thermal systems. It can also be used to review procedures and other sequential or batch operations.

Further guidance on risk assessments techniques can be found in the following references:

- ABS *Guidance Notes on Risk Assessment Applications for the Marine and Offshore Oil and Gas Industries*
- ABS *Guidance Notes on Failure Mode and Effects Analysis (FMEA) for Classification*
- *Petroleum and Natural Gas Industries – Offshore Production Facilities – Guidelines on Tools and Techniques for Hazard Identification and Risk Assessment, ISO 17776*
- *Risk Management – Risk Assessment Techniques, ISO 31010*
- *Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment, SAE ARP 4761*

9.3 Engineering Evaluation

Engineering evaluations are used to verify and validate that the new technology is capable of performing acceptably with respect to intent and overall safety according to the requirements of each stage. This is achieved gradually for each qualification stage through specific qualification activities as the technology matures and can be found in the NTQP. The types of activities for engineering evaluation are:

i) *Review Engineering Design Requirements.* As the technology matures, and more detailed design information becomes available, the functional and performance requirements are reviewed/updated as needed.

ii) *Technical Analyses and Simulations.* Engineering design analyses and simulations are used to verify the technology at the earlier qualification stages

iii) *Validation Testing.* Functional, model testing, and prototype testing are used to verify that the new technology satisfies all the specified functional and performance requirements.

iv) *Interface Analyses.* Interface analyses of the technology with existing systems are required and system integration testing is needed in order to fully understand all interactions between the new technology and surrounding systems, including people and the environment.

v) *Verification of Operability.* Operational testing and the collection of test data are required to verify the new technology satisfy the operational requirements.

vi) *Verification of Inspectability and Maintainability.* The various components of the new technology must be reviewed to confirm that they can be monitored, inspected and maintained in a manner consistent with existing practice.

vii) *Quality Assurance and Quality Control (QA/QC) Program.* Establish and maintain an effective quality control procedure(s) and quality acceptance criteria at each stage in accordance with recognized industry standard.

9.5 Design Improvements

Based on the results of the engineering evaluation and risk assessment activities, design improvements may be necessary to enhance reliability and safety of the design. The opportunities to improve safety could be through changes or modifications that make the design inherently safer or implementation of appropriate risk control measures. Example design changes include, material changes, reconfiguration, redundancy, and loading requirements.

Any design improvements that are identified and determined necessary as part of further refinement of the new technology is to be re-evaluated against the functional and performance requirements outlined in SRDD. The updated qualification activities should aim to meet these new requirements. Design improvements should be tracked in the NTQP.

The following sections should be considered when improving the design of any new technology.

9.5.1 Hierarchy of Risk Control Measures

Inherently safe design exists in something as a permanent and inseparable element. In other words, the risk control measures in place are "built in", not "added on". Identification of measures to control risks identified throughout the qualification process can be summarized in the following list:

i) *Elimination or Substitution.* Elimination of the design element, or the hazard associated with it should always be the first consideration. Careful evaluation may indicate that the functional requirements may be accomplished by another design element.

ii) *Engineering.* Engineering controls are mechanical or physical features added to the equipment, systems, subsystems, and/or components in order to remove or control the hazard, either by initial design specifications or by applying methods of substitution, minimization, isolation, or ventilation.

iii) *Administrative.* Administrative controls rely more actively on human action and behavior. Examples of administrative controls include written operating procedures, maintenance and inspection strategies, checklists, safety meetings, alarms, signs, training of personnel.

iv) *Personal Protective Equipment.* Personal protective equipment (PPE) creates a barrier between the person wearing the PPE and the hazard associated with the job. PPE such as hearing protection, protective clothing, safety glasses, respirators, gloves, welding aprons, and hardhats are methods of controlling hazards.

In general, inherently safe design is more of a philosophical way of thinking rather than a specific set of tools or methods. For example, a hazard might be considered "safe" because it has specific risk reducing measures in place. Inherently safe design asks the question, "can it be safer?"

The goals of inherently safe design can be summarized by the following:

- Fewer and smaller hazards
- Fewer causes that initiate hazardous events
- Reduced severity and consequences (e.g. fatalities, lost time incidents, asset damage, etc.)
- More effective management of residual risk

The inherently safe design approach to achieve goals of safer design should consider elimination or substitution to significantly reduce hazards. The following questions should be asked when considering the design of new technologies with hazardous potential:

1. Can the hazard be eliminated by design improvements?
2. If not, then can the magnitude of the hazard be reduced?
3. Do the alternative designs identified in question 1 and 2 increase the magnitude of other hazards or present new hazards?
4. What other risk control measures (engineering or administrative) are required to manage hazards that remain?

An inherently safe design approach to design improvements is recommended in order to eliminate design elements that are limiting the new technology from meeting defined functional and performance criteria. This philosophy should shift focus on improving design by implementing elimination, substitution, or engineering risk control measures.

9.5.2 Management of Change

Design improvements are inevitable during the course of technology design and development and are integral to the process, especially during the early design phases. These improvements can potentially have an impact on risk, and on previously performed qualification activities during the NTQ process. For this reason, it is important that clients establish an appropriate Management of Change (MoC) program. It is recommended that a MoC program be developed to confirm that design improvements are reviewed in a responsible manner by appropriate personnel.

A MoC program is a combination of policies and procedures used to evaluate the potential impacts of a proposed design improvement so that it does not result in unacceptable risks. Developing an effective MoC strategy requires establishing, documenting, and successfully implementing formal policies to evaluate and manage both temporary and permanent modifications including equipment, materials, procedures and conditions.

The techniques used to evaluate the improvement, the people available for review, the time frames for reviewing and implementing the improvement will differ between the design phases. During the early phases, there may be many design improvements, but there will be fewer records to update than if the improvement occurs at a later stage. Tools such as software simulations and preliminary risk analysis can prove extremely valuable when determining design improvements at early stages and are less labor intensive than in later stages.

An effective MoC program requires preparation beyond defining and documenting a policy to outline the system. The following factors are important to successful implementation of a MoC program:

i) Clear roles and responsibilities

ii) Appropriate organizational preparation

iii) A written MoC program manual that includes MoC forms

iv) Pilot roll-out before the full-scale deployment, training of affected personnel, and

v) Close attention when integrating MoC with existing programs.

The following references provide more details on Management of Change processes:

- ABS *Guidance Notes on Management of Change for the Marine and Offshore Industries*
- *API RP 750, Management of Process Hazards, American Petroleum Institute, Washington, DC, 1990*
- *API RP 75, Recommended Practice for Development of a Safety and Environmental Management*
- *Program for Offshore Operations and Facilities, American Petroleum Institute, Washington, DC, 2004*
- *Guidelines for Management of Change for Process Safety, Center for Chemical Process Safety CCPS, 2008*

SECTION 3 Feasibility Stage

1 Introduction

A new technology considered for qualification in the Feasibility stage is at an early concept maturity level, where basic research and development activities to identify engineering principles are complete; and a concept formulated along with its functional requirements. A high-level design analysis is performed to verify the concept in the intended application and that the overall proposed level of safety is comparable to those established in Rules, Guides, other recognized industry standards and recommended practices.

In cases where multiple concepts are submitted for ABS review, the overall objective is to work with ABS to identify a concept that proves most feasible for the application with respect to safety and reliability.

3 Qualification Activities

3.1 Engineering Evaluation

The engineering evaluation at the Feasibility Stage involves a high-level design verification of the proposed concept. All goals, functional requirements, and performance requirements submitted as part of the SRDD in 2/3.3 are reviewed along with any available high-level engineering design analysis to verify that the proposed concept is feasible.

3.3 Risk Assessment

A high-level risk assessment should be carried out during this stage to identify any preliminary technical risks and uncertainties associated with the proposed concept. The risk assessment should focus on documenting all foreseeable hazards, their causes, consequences, and potential risk control measures considering the new technology in its proposed application and operating environment. Additionally, all possible interfaces and known integrations should be considered. This risk assessment should set the basis for any subsequent qualitative/quantitative assessments that may need to be performed to completely understand the new technology's risk profile. Subsequent assessments may be in the form of additional engineering evaluation or risk assessments.

The results of the risk assessment should be documented and tracked in a hazard register for assessment and implementation in future qualification stages. The primary function of the hazard register should be to demonstrate that hazards and appropriate risk control measures have been identified. Recommendations for additional risk assessments and engineering evaluations are to be documented and submitted as part of the NTQP.

An appropriate risk assessment technique should be selected for this high-level risk assessment and submitted to ABS for review in the form of a risk assessment plan as discussed in 2/9.1. The engineering evaluation documents that support the risk assessment should be available and at an appropriate level of maturity before the risk assessment is performed. The following high-level risk assessment techniques are recommended as options for identifying preliminary technical risks:

i) HAZID identifying possible hazards, events, and outcomes related to the impact on personnel, asset, environmental, and reputation

ii) Functional FMEA identifying possible failure modes, effects (local and global), causes, and preliminary safeguards including all interfaces (i.e. system to system, system to subsystem, etc.)

iii) Functional Hazard Analysis (FHA) identifying system/sub-system functions and hazards associated with those functional failures

A risk assessment report including the hazard register should be prepared. The risk assessment report and the NTQP should be submitted to ABS for review.

There may be specific cases where the information available at this maturity level is limited and a risk assessment technique may not be possible. This scenario will be treated on a case-by-case basis, and ABS will recommend an alternative approach as needed to meet the new technology Feasibility Stage requirement.

5 Summary of Submittals

The following qualification activities along with future activities for the Concept Verification Stage should be highlighted in the NTQP and submitted to ABS for review:

5.1 Engineering Evaluation

i) SRDD

- Design basis, functional specification and/or technical specification of the new technology
- System and function architecture details such as functional flow block diagram
- Design details such as basic engineering drawings and engineering principles associated with further development
- Design analysis methodology and any available preliminary results
- Details regarding physical and functional interface requirements (mechanical, hydraulic, electronic, optical, software, human, etc.)
- Applicable design references, codes, standards and guidelines, and technical justification for any proposed deviations (may be identified independently or during the new technology screening process)
- Lessons learned, references and examples of comparable designs

5.3 Risk Assessment

i) Risk assessment plan in accordance with 2/9.1

ii) The appropriate risk assessment report identified in 3/3.3

iii) Hazard Register complete with an action tracking system

7 Feasibility Stage Completion: Technology Feasible

Once the above deliverables have been submitted to ABS for review and all specified performance requirements have been verified, then a Statement of Maturity will be issued stating that the technology is feasible. The technology is now ready to proceed to the Concept Verification Stage.

SECTION 4 Concept Verification Stage

1 Introduction

The second stage of the NTQ process is the Concept Verification Stage. The new technology is verified as performing its functions in accordance with defined performance requirements. This is accomplished by performing more detailed engineering studies and physical (or virtual) model testing. Reliability testing of select items may be performed. The operating conditions and the relevant environment are further refined. The functional and performance requirements outlined in the SRDD are re-evaluated, verified, and updated (as needed). The interfaces between configurations are verified against functional and performance requirements.

In addition, the production strategy is developed in the form of a preliminary manufacturing plan. A design risk assessment is carried out to identify technical risks related to design failures. Risk assessments from the Feasibility Stage are reviewed and updated (as needed) based on the design development in this stage.

3 Qualification Plan Activities

3.1 Engineering Evaluation

3.1.1 Engineering Design Review

At the Concept Verification Stage, the concept is confirmed and the engineering design is performed to verify that the functionality and performance of the new technology can be satisfied. The subsystem and component level requirements following the systems engineering approach should be defined if not specified at the Feasibility Stage. The objective is to define complete and consistent requirements that an item should have and confirm that the design correctly and completely captures each specification in the system requirements.

The performance requirements should state how the technology will perform its function and how the system requirements will be met. The performance requirements are to be established and should be detailed enough that the technology can be evaluated against the expected performance criteria. In addition, the requirements for the integration of subsystems and components into system prototypes should be defined. The overall configuration of the system should be provided and a preliminary interface analysis should be performed to verify the interfaces between configurations.

Design constraints should be identified and incorporated into the system requirements and design documentation. At this stage, the system requirements should be stated in quantitative measures that can be verified by subsequent numerical or analytical models and model tests. The overall system requirements defined at the Feasibility Stage should be reviewed to confirm continued relevance. Any change should be reviewed and documented with technical justification.

A preliminary manufacturing plan should be developed and should include the manufacturing methods and processes, the facilities, the production schedule, and the quality assurance requirements. The materials used in the system should be determined and reviewed during the qualification process. The technology design documentation is to be submitted for ABS review.

3.1.2 Functional and Model Testing

Tests are an essential part of the NTQ process and they can demonstrate the performance of the new technology. The types of tests required depend on the novelty of technology itself and pre-existing experience with similar concepts.

Functional and model tests are used to verify the functionality of the system and its ability to meet the defined functional requirements. Testing is to be performed in the technologies anticipated environment and operating conditions. The objectives of the functional testing are to verify that the system meets the performance and reliability requirements, as well as to verify the results obtained from the analytical models. The functional testing should consider and address the critical failure modes identified during the risk assessments.

For the new materials or those that can have a significant effect on the performance of the system, destructive or non-destructive testing should be used to identify the relevant failure modes and mechanisms or to explore the critical parameters and their effects. The same raw materials or components stated in the material specification for the actual product should be used in the tests. For materials that will degrade over time, materials degradation testing should be performed. Accelerated testing methods may be used to test the lifetime performance of the materials in a shorter time. Additionally, reliability testing for select items may be required.

Before performing any testing, a test plan should be developed and submitted to ABS. The test plan should document the test setup and strategy that will be used to verify that a product meets its design specifications and other requirements. The specific test plans should include the assumptions and constraints, input data, test procedures, expected test results, the parameters to be measured, instrumentation system specifications, and the acceptance criteria for evaluating results. For certain tests, it may be required for an ABS Surveyor to witness the testing activities to verify that it meets performance requirements and confirm the presence of an effective quality control program. Further guidance on function and model testing can be found in references [10], [11], [12] and [13] listed in Appendix 1.

3.3 Risk Assessment

The objective of the risk assessment in this stage is to identify technical risks associated with the new technology design to the lowest level of indenture as practicable. The updated concept level design engineering documentation from the Feasibility Stage and the additional engineering documents developed in this stage serve as input to the risk assessment. This design risk assessment should take into account the following:

- Any design modifications from the Feasibility Stage
- Updated functional and performance requirements
- Updated configurations
- Possible interfaces and integrations
- All potential failure modes, failure causes and failure mechanisms in all expected operational modes and life cycle stages
- The effectiveness of existing risk control measures and the need for any additional or more reliable measures
- Closing out any action items (qualification activities) as agreed in the Feasibility Stage

Based on the findings of this risk assessment, additional qualification activities in the form of risk assessments or engineering evaluation may be required to further assist in identifying and assessing the full potential ranges of failure causes, failure mechanisms, consequences and any related uncertainties. These additional studies may be coarse, detailed, or a combination depending on the objective of the study. The results of the risk assessment should be documented and tracked in a hazard register for assessment and implementation in future qualification stages. The resulting qualification activities should be documented within the NTQP. A risk assessment report including the hazard register should be prepared. The risk assessment report and the NTQP should be submitted to ABS for review.

A risk assessment technique that is appropriate for reviewing the new technology design should be selected and submitted as part of the risk assessment plan to ABS. Potential design related failure events in all anticipated operational modes should be evaluated. Typically, for hardware or mechanical systems, a Failure Mode Effects and Criticality Analysis (FMECA) is recommended. The FMECA performed can help evaluate failure modes and corresponding failure causes, failure mechanisms, and the local and global effects of failure. It also includes a criticality analysis which is used to estimate the probability of failure and the severity of the associated consequence. The probability can be qualitative if lacking historical quantifiable data, but quantitative probabilities are preferred. The method of assigning criticality should be included within the risk assessment plan and agreed by ABS prior to the study. Results from the FMECA should be relayed back to the design process of the new technology to facilitate any design improvements or FMEA verification activities. Further guidance on FMECA and related verification activities can be found in the ABS *Guidance Notes on Failure Mode and Effects Analysis for Classification.*

The following risk assessments verifying all technical risks are to be performed and submitted to ABS for review.

i) Design risk assessment (e.g., FMECA) as described above.

ii) Update Feasibility Stage risk assessments as needed based on updated design documentation.

iii) Perform any additional risk assessments identified while verifying the design and/or updating previous risk assessments.

If reliability, availability and maintainability (RAM) targets are defined as part of the functional requirements then a preliminary system RAM analysis should be carried out in this stage. System modeling techniques such as reliability block diagrams (RBD), fault tree analysis (FTA), Markov state diagrams or other established methods should be used to demonstrate the ability of the system to meet the defined performance requirements. The FMECA serves as input to the system reliability models along with the other engineering documentation developed at this stage. A RAM analysis should be prepared and submitted for ABS review. The data sources used, their applicability and any related assumptions should be documented within this report.

5 Summary of Submittals

The following qualification activities along with future activities to be addressed in the Prototype Validation Stage should be highlighted in the NTQP and submitted to ABS for review:

5.1 Engineering Evaluation

i) SRDD

- *a)* Documents that describe the concept verification design requirements
- *b)* Design documents that include but not limited to the configuration, drawings, PFD/P&ID, analytical models, etc.
- *c)* Functional and model test plans, test data (as requested), and test results

ii) Preliminary manufacturing plan

5.3 Risk Assessment

i) Updated risk assessments from the Feasibility Stage (as applicable)

ii) Updated Hazard Register with updated action items closed out

iii) Preliminary design risk assessment (e.g., FMECA) report

iv) Preliminary system RAM analysis report (as applicable)

7 Concept Verification Stage Completion: Concept Verified

Once the above have been submitted to ABS for review and all specified performance requirements have been verified, then a Statement of Maturity will be issued stating that the concept has been verified. The technology is now ready to proceed to the Prototype Validation Stage.

SECTION 5 Prototype Validation Stage

1 Introduction

The third stage of the NTQ process is the Prototype Validation Stage. New technology that has matured to this stage has previously completed conceptual functional, performance, and reliability testing in nonspecific environments. The main objective in this stage is to validate with a prototype what was verified in the Concept Verification Stage.

During this stage, the technology is further developed to the point where a prototype or full scale production unit can be manufactured. All engineering studies and design risk assessments are completed and the design is refined to the detailed design. Engineering documents such as detailed drawings, product specifications, manufacturing plan and qualification test procedures are all fully developed. A preliminary system-of-systems interface analyses may be performed and system integration testing plan developed. Process risk assessments may be carried out (as needed) to evaluate relevant procedures and further refine them.

A prototype or full scale production unit is manufactured and all necessary qualification testing is carried out to validate the design. After completing this stage, the new technology has demonstrated that it can perform within the established performance requirements in a simulated or actual environment for an extended period of time.

3 Qualification Plan Activities

3.1 Engineering Evaluation

3.1.1 Engineering Design Review

At the Prototype Validation Stage, the engineering design is to confirm that the overall system, down to the lowest component level, has satisfied all system requirements. The performance requirements a technology must meet should be finalized and measurable. In addition, the requirements for system integration, installation, commissioning, operation, maintainability, and decommissioning should be established.

At this point the system has reached the necessary level of maturity to start fabricating, integrating, and testing. Changes in the requirements defined for any items during the previous stages should be reviewed and documented with technical justification.

At this stage, all design analyses and configuration definitions are completed and all design decisions that are outstanding are to be finalized. It is noted that there may be a need to revisit certain analytical and other relevant studies based on results of the prototype test. Detailed drawings including all dimensional requirements, process and instrument details, safety features and ancillary systems are completed as applicable. For load bearing components, all relevant loading and the uncertainty in that loading are analyzed. For process and electrical systems, all associated potential system failure/breakdowns and their associated failure frequencies (if applicable), as well as the consequence and impact on the system from each failure are identified.

In addition, all information (e.g., drawing and data) required for the production of the system are to be finalized. The actual performance of the new technology should be evaluated during prototype testing and compared against existing designs if available. The aforementioned design engineering documents are to be submitted to ABS for review. A preliminary system-of-systems interface analyses and system integration testing plan may be developed at this stage and submitted to ABS for review before the System Integration Stage.

3.1.2 Prototype Testing

Prototype testing is intended to prove that the interactions between the systems/subsystems/components under relevant loading and environmental operating conditions can perform reliably as intended. Prototype tests can identify potential failure modes and mechanisms as well as the critical parameters, especially when operational experience in relevant environments is limited or unknown.

Prototype testing can be used to verify the analytical models and the assumptions made during the engineering design process. A test plan which details test techniques, test limits, expected test data, quality assurance requirements should be developed and submitted to ABS for review before prototype testing. Calibration of measuring devices is to be current with manufacturer’s quality management system. Calibrations should be traceable to a recognized national standard (e.g., NIST, ANSI, etc.).

For certain new technologies, it may be very difficult to perform prototype testing in the actual environment. In this case, virtual prototype testing in a simulated environment can be performed. However, the virtual prototype testing must be reviewed by ABS to assess that the simulated environments are commensurate with expected operational practices. Analysis tools, such as finite element analysis (FEA) and computation fluid dynamics (CFD), and other methods used should be qualified for application. The prototype testing documents should include inputs, assumptions, boundary conditions, the computational models and appropriately conditioned/reported test results. Prototype test results should be documented and analyzed to determine whether the prototype satisfies specified functional and performance requirements in its actual environment. A prototype test report is to be submitted to ABS for review. Further guidance on prototype testing can be found in references [10], [12], [13] and [14] listed in Appendix 1.

3.1.3 Manufacturing

A manufacturing plan should be finalized that includes the manufacturing methods and processes, the facilities, the production schedule, and quality assurance requirements. Quality assurance of the manufacturing process should confirm that the product meets the required specifications. The manufacturing plan should be submitted to ABS for review. Further guidance on developing a manufacturing plan can be found in references [15], [16] and [34] listed in Appendix 1.

3.1.4 ABS Survey

Survey during the manufacturing process and prototype testing may be required. The vendor should submit an Inspection Test Plan (ITP) to ABS for review. The ITP should define witness points and hold points as agreed between the vendor and ABS. The ABS Surveyor should witness the manufacturing process and prototype testing to verify that proper manufacturing and prototype testing processes are followed and it meets the quality assurance requirements.

3.3 Risk Assessment

The main objective of the risk assessments performed in the Prototype Validation Stage is to validate the final design of the new technology. The design risk assessment (e.g., hardware design FMECA) from the Concept Verification Stage should be reviewed and updated to evaluate changes made to the design and/or other aspects of the new technology description. Changes made to one part of the design or new technology design requirements could have the potential to introduce new technical risks to other previously evaluated parts. The results of other qualification activities in this stage may also serve as input to the updated design risk assessment. Follow-on qualification activities determined from the results of the updated design risk assessment should be included within the NTQP.

For certain new technologies with high consequence severity levels upon failure, if not already addressed by other risk assessments, ABS may recommend that an additional process risk assessment (e.g., process FMECA or HAZOP) is performed. The objective of this risk assessment is to evaluate the potential failures that could occur during specific steps as listed within the procedures. This process risk assessment typically evaluates procedures related to manufacturing (as defined within the final manufacturing plan), testing (prototype and systems integration), installation/integration, commissioning, operations and decommissioning. A risk assessment technique that is appropriate for reviewing these procedures should be selected and submitted as part of the risk assessment plan to ABS for review. Typically, a process FMECA or HAZOP study is recommended. It is recognized that the scope of this risk assessment depends on the availability of relevant procedures. All interfaces should also be considered when performing this assessment. The recommendations from the study should be used by the engineering design team and the operations team to determine any design improvements or procedural changes necessary before finalizing the design and manufacturing.

Based on the findings of the final design risk assessment and process risk assessment (if applicable), a re-evaluation of all previous risk assessments should be considered. All previous risk assessments should be reviewed against any newly identified failure modes or hazards. Changes made to the design due to findings in these risk assessments should also be checked against the final functional and performance requirements.

Finally, all identified technical risks from the Prototype Validation Stage and risk assessments from previous stages should be appropriately managed through any necessary design improvements. All corresponding action items should be closed in order for the new technology to complete this stage of the NTQ process.

The following final design level risk assessments verifying all technical risks are to be performed and submitted to ABS for review:

i) Final design risk assessment (e.g., design FMECA)

ii) Final process risk assessment (e.g., process FMECA or HAZOP) if applicable

iii) Update all previous risk assessments as needed based on updated final design level documentation

iv) Final hazard register based on the final design with all actions items closed out

If applicable, the preliminary RAM analysis should be re-evaluated and finalized. The final RAM analysis report should be submitted for ABS review.

5 Summary of Submittals

The following qualification activities along with future activities for the System Integration Stage should be highlighted in the NTQP and submitted to ABS for review:

5.1 Engineering Evaluation

i) SRDD

- Review engineering documents that describe the component requirements and the interaction between components, subsystems, and the overall system if applicable.
- Detailed design documents including detailed drawings, product specifications, process and instrument details, detailed calculations, etc.
- Prototype test plans, test data (as requested), and test results summarized in a report.
- Additional qualification testing, data, and results identified in the design risk assessment (e.g., FMECA).

ii) Inspection Test Plan (ITP)

iii) Detailed manufacturing plan.

5.3 Risk Assessment

i) The final updated risk assessment reports from the Concept Verification Stage (as applicable).

ii) The final design risk assessment (e.g., FMECA) report.

iii) The process risk assessment (e.g., process FMECA) report (as applicable).

iv) The final system RAM analysis report (as applicable).

v) Final hazard register with all action items closed out.

7 Prototype Stage Completion: Technology Qualified

Once the above deliverables have been submitted to ABS for review and all specified performance requirements have been verified, then a Statement of Maturity will be issued stating that the technology has been qualified. The technology is now ready to proceed to the System Integration Stage.

9 ABS Type Approval Program

Upon completion of the Prototype Validation Stage of the NTQ process, the new technologies that are consistently manufactured to the same design and specification may be Type Approved under the ABS Type Approval Program to limit repeated evaluation of identical designs. During the Prototype Validation Stage, if all the engineering evaluations have been completed, a PDA can be issued prior to further consideration for ABS Type Approval.

SECTION 6 Systems Integration Stage

1 Introduction

The fourth stage of the NTQ process is the Systems Integration Stage. In this stage, discussions between the vendor and end-user are held to understand the compatibility of the technology with final operating system and operating environment. An interface analysis is performed to confirm the compatibility of the item. The technical risks during operations that have not been addressed during previous risk assessments are evaluated and relevant reports updated. All necessary risk control measures are implemented.

The "Technology Qualified" item is then integrated (by installation) with the final intended operating system. All functional and performance requirements of the integrated system as outlined in the SRDD are validated through testing before (or during) commissioning. Plans for in-service survey, inspection, monitoring, sampling and testing (as applicable) are determined.

3 Qualification Plan Activities

3.1 Engineering Evaluation

3.1.1 System Interface and Integration Requirement

At this stage the overall technology goals and requirements may remain unchanged. However, specific requirements for system-of-systems functionality and interfaces should be finalized. In addition, the detailed operational performance parameters should be defined and operational procedures should be developed. System interface and integration requirements are to be submitted to ABS for review.

3.1.2 Interface Analysis

It should be analyzed that the addition or incorporation of the new technology does not negatively affect the integrity of the surrounding systems and components. All necessary functional and physical interfaces (e.g., mechanical, electrical, environment, data, human, etc.) and other systems should be reviewed and verified that the new technology does not adversely affect those systems. At this stage, the interfaces should be specified in quantitative limiting values, such as interface loads, forcing functions, and dynamic conditions. The use of tables, figures, or drawings is recommended as appropriate. The vendor/end-user should provide detailed interface control methods or other engineering solutions so that the new technology is compatible with the integrated systems. The complete interface analysis and necessary engineering solutions are to be submitted to ABS for review.

3.1.3 System Integration Testing (SIT)

The operational prototype is built and integrated into the final system. Full interface and function test programs are performed in the intended (or closely simulated) environment. The impact of the new technology on the performance and integrity of other systems as well as the impact of other systems on the new technology itself should be addressed. An initial operational test and evaluation should be performed to assess the operational effectiveness and suitability in the intended environment. The operational test must demonstrate that the operational aspects associated with placing the application in a marine or offshore environment are commensurate with typical operational practice for these facilities. Changes to the technology design or operational procedures may be necessary to address any issues encountered during operational testing. A test plan which details test techniques, test limits, expected test data, quality assurance requirements should be developed and submitted to ABS for review before the system integration testing. All test procedures and test results are to be summarized in a report and submitted to ABS for review.

3.1.4 ABS Survey

Survey during the system integration testing may be required as agreed upon in the system integration test plan. ABS Surveyor will witness the system integration testing to verify that proper testing processes are followed and it meets the quality assurance requirements based on the witness points as agreed between the vendor/end-user and ABS.

An In-Service Inspection Plan (ISIP) to address in-service survey, inspection, monitoring, sampling and testing (as applicable) during operations should be submitted for ABS review.

3.3 Risk Assessment

The main objective of the risk assessments performed in the System Integration Stage is to evaluate any technical risks resulting from system integration and operations that have not been previously evaluated as part of the design risk assessment, process risk assessments or other risk assessments in the previous stages. The end-user should manage any additional/residual risks identified through appropriate risk control measures.

An appropriate risk assessment technique should be selected and submitted as part of the risk assessment plan to ABS for review. The use of a process FMECA, HAZOP or HAZID are recommended. The scope of this risk assessment typically includes installation, SIT, commissioning, operations and decommissioning. The assessment should consider all interfaces between the validated prototype and the connected system (system-of-systems). Follow on qualification activities may be determined from the results of the risk assessment such as engineering evaluation, testing, design improvements or procedure changes. These activities should be addressed within the NTQP. All risk control measures should be implemented and any outstanding action items from the risk assessment closed before proceeding with system integration testing and commissioning.

The need for updates to any previously submitted risk assessments or RAM analysis should be evaluated and addressed as appropriate. Updated risk assessment reports including hazard registers, RAM analysis (if applicable) and the NTQP should be submitted for ABS review.

5 Summary of Submittals

The following qualification activities along with future activities for the Operational Stage should be highlighted in the NTQP and submitted to ABS for review:

5.1 Engineering Evaluation

i) SRDD

- All documents that describe requirements for system-of-systems functionality and interfaces.
- All documents that describe detailed operational procedures and performance parameters.
- System integration test plans, test data, and test results summarized in a report.
- Plans for in-service survey, inspection, monitoring, sampling and testing (as applicable) during operations or ISIP.

5.3 Risk Assessment

i) Updated risk assessment reports from the previous stages (as applicable)

ii) Other applicable technical safety studies (e.g., RAM).

7 System Integration Stage Completion: Technology Integrated

Once the above deliverables have been submitted to ABS for review and all specified performance requirements have been verified, then a Statement of Maturity will be issued stating that the technology is integrated. The technology is now ready to proceed to the Operational Stage.

SECTION 7 Operational Stage

1 Introduction

The last stage of the new technology qualification process is the Operational Stage. New technology categorized as "Operationally Qualified" denotes that it has been integrated into the final system and has been operating successfully in service in the relevant operational environment.

Once the technology has been qualified at the Prototype Stage, it must be confirmed that the knowledge gained by the engineering and risk assessment tests and studies is fed into the operational stage, in order to monitor prior assumptions and predictions through in-service field verification. In other words, the first implementation of any new technology should be treated as a first time application to some extent. This Section will outline the necessary activities that must be completed and the information to be supplied to ABS during this stage. It is recommended that the qualification process involves members with operational background in this stage of the project. These members should become familiar with the results of all the previous qualification stages, if they had not participated from the start of the qualification process.

At this stage, the operational objectives, operating environment and the performance requirements established during design are reviewed and applied to define goals for in-service operation. Following successful operation and performance achievement of the goals in the actual operational environment, the technology can be granted a Statement of Maturity.

The activities of the Operational Stage are as follows:

i) Implementation of in-service survey, inspection, monitoring, sampling and testing plans

ii) Collection and analysis of reliability, availability, maintainability (RAM analysis) and other operational performance data as needed

iii) Comparison of operational data above with previously specified performance requirements, goals and criteria

iv) Performance of root cause analyses for any observed failure and using feedback to introduce modifications for improvement

v) Comparison of observed parameters with any critical assumptions made during the previous qualification stages and updating calculations as necessary

It is to be noted that when applying these Guidance Notes for classification or certification purposes, the primary driver for classification acceptance will be safety even though there may be additional functional requirements (e.g., reliability, ability to perform as per operational design specification) defined by the client.

3 Qualification Plan Activities

The need and extent of special in-service qualification requirements are dependent upon the justifications and risk assessment results during the design and qualification process. System requirements have been started to be defined in the Feasibility Stage of qualification, and they have been updated in later stages as the design evolved. Such requirements have to be translated into specific and quantifiable performance requirements to be attained during operations. Additionally, any critical assumptions made in the risk assessment and engineering evaluations during the four previous qualification stages should be monitored to confirm that operational experience does not disprove them. Taking all the above into consideration, the vendor and/or end-user together with ABS should outline the necessary elements of in-service survey, inspection, monitoring, sampling and testing needed to gain confidence in the real world application of the new technology.

These special requirements can be integrated in the end-user's Asset Integrity Management program. Advanced inspection and maintenance approaches like Reliability Centered Maintenance (RCM) and Risk Based Inspection (RBI) are appropriate strategies to follow since they are based on reliability and risk goals. Data collection and management are very important activities to consider for the in-service qualification stage.

The amount of operational history that is sufficient to verify performance requirements during operations depends on several factors, including actual equipment run time, failure rate and exposure time to failure. Therefore, the time to reach the "Operationally Qualified" status for the proposed new technology will be determined on a case-by-case basis.

All records related to the inspection, monitoring, sampling and testing of the new technology as established by the agreed-upon operational qualification plan or ISIP should be kept and made available for review upon request by ABS at any time. These records will be reviewed periodically to establish the scope and content of the required surveys that should be carried out by ABS.

The following references contain additional guidance for in-service monitoring, sampling, testing and inspection plans:

- ABS *Guidance Notes on Equipment Condition Monitoring Techniques*
- ABS *Guidance Notes on Reliability-Centered Maintenance*
- ABS *Guide for Surveys Using Risk-Based Inspection for the Offshore Industry*
- ABS *Guidance Notes on the Investigation of Marine Incidents*
- ABS *Guide for Hull Condition Monitoring Systems*
- ABS *Guide for Hull Inspection and Maintenance Program*
- ABS *Guide for Building and Classing Subsea Pipeline Systems*
- API RP 17N *Recommended Practice Subsea Production System Reliability, Technical and Integrity Management*

5 Summary of Submittals

The output of this stage is a report reviewing the operational data collected, and demonstrating how the specified performance requirements and criteria have been met.

The following items are typical submittals that ABS would expect to receive annually in order to conduct an Operational Stage audit:

- Summary report of results of the inspection, monitoring, sampling and qualification testing activities
- Failure data analysis of critical components
- Non-conformance reports and corrective actions taken.

Note: In case of a non-conformance report for a critical component, ABS should be notified as soon as practical.

7 Operational Stage Completion: Operationally Qualified

Once the operational experience of the new technology has proven to be successful (i.e., according to the expected performance, for a satisfactory amount of time in the actual operating environment, and meeting criteria acceptable by ABS), then a Statement of Maturity stating the operational qualification of the technology will be issued.

APPENDIX 1 References

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APPENDIX 2 Comparison of ABS Qualification Stages with Industry TRLs

1 Introduction

Technology Readiness Levels (TRLs) are a method of estimating the maturity level of new technology. There are a wide variety of scales in industry based on the ISO 16290 standard. This standard uses a numerical scale one through nine, with nine representing the most mature. The American Petroleum Institute (API) uses a scale ranging from zero to seven. Although the definitions of these levels differ slightly (space systems vs oil and gas), the fundamental philosophy remains the same. ABS has developed a stage gate process compatible with the wide range of TRLs (API, US DoD, ISO 16290). However, the numbers levels presented have now been replaced by a series of qualification stages. Comparison of the ABS definition and the industry TRLs are provided in the table below.

TABLE 1
ABS Qualification Stages Comparison with Various Industry TRLs

ABS Qualification Stage	*API RP 17N/Q TRLs*	*US DoD TRLs*	*ISO 16290 TRLs*
Feasibility Stage	0	1	1
	1	2	2
Concept Verification Stage	2	3	3
		4	4
Prototype Validation Stage	3	5	5
	4	6	6
System Integration Stage	5	7	7
	6	8	8
Operational Stage	7	9	9

APPENDIX 3 New Technology Stage Determination

1 Introduction

In order to estimate the current qualification stage of a proposed a new technology, the following table should be used. These questions serve as general guidance to understand the design maturity of the technology based on completed qualification activities and hence determine the corresponding qualification stage. The client's design team, ABS, and other identified stakeholders should agree upon the qualification stage identified. All supporting documentation justifying affirmative answers are to be submitted to ABS for review. Negative answers will be reviewed on a case-by-case basis in order to determine applicability of the question to the technology.

Qualification Stage	*Item #*	*Question*	*Yes/No/NA*	*Evidence to support?*
Feasibility Stage	1	Has what is specifically new and/or unique about the concept been clearly identified?		
	2	Has what specifically needs qualification been defined?		
	3	Have potential applications been identified?		
	4	Have fundamental objectives and requirements (e.g., RAM) for the identified application been identified?		
	5	Have basic functionality and durability of the technology been analyzed?		
	6	Have basic principles been observed and reported?		
	7	Have lessons learned from similar technology been reviewed and documented?		
	8	Have basic design calculations been performed?		
	9	Have conceptual research and development been completed?		
	10	Has a preliminary list of reliability drivers been prepared?		
	11	Has a preliminary fitness assessment (physical interfaces, human etc.) been performed?		
	12	Can engineering drawings (basic configurations, interfaces, and/or PFD's or flow charts) and calculations be submitted for review?		
	13	Have any early stage risk assessment and mitigation studies been performed and documented?		
Concept Verification Stage	14	Has the concept functionality been demonstrated by physical models or "mock-ups"?		
	15	Have laboratory scale material testing and degradation mechanisms been performed?		
	16	Have all conceptual design engineering studies been completed?		
	17	Have preliminary function/performance/reliability engineering studies been completed?		
	18	Have reliability drivers been confirmed?		
	19	Is there documentation that RAM requirements can likely be met?		
	20	Has durability been confirmed by testing or calculation?		
	21	Has a viable manufacturing or fabrication scheme been documented?		
	22	Has preliminary qualitative design risk analysis (e.g., FMECA) been documented?		
	23	Have the initial risk assessments been reviewed/updated to identify any additional technical risks?		

Qualification Stage	*Item #*	*Question*	*Yes/No/NA*	*Evidence to support?*
Prototype Validation Stage	24	Have all items in the manufacturing of the technology been specified?		
	25	Has the manufacturing and assembly process been accepted?		
	26	Has a prototype or full scale production unit been manufactured?		
	27	Has the manufacturing and assembly defects been removed by stress screening?		
	28	Has the technology passed basic functionality testing of prototype (physical or virtual) or full scale product to demonstrate fitness and function capability in a simulated or actual operating environment?		
	29	Has a performance data collection system been established and properly documented?		
	30	Has the technology passed performance, durability, and accelerated life tests?		
	31	Is the degradation of function/performance within expected acceptable limits?		
	32	Has the technology passed system reliability analyses?		
	33	Has the operating/destruct limits been established or confirmed?		
	34	Has the degradation limits and rates been established or confirmed?		
	35	Has the required in-service monitoring needs and means been identified?		
	36	Has a process risk assessment (e.g., process FMECA) been performed and documented (if applicable)?		
	37	Has the final design risk assessment (e.g., FMECA) been completed for all life cycle modes (including assembly, transit, storage, installation, hook-up, commissioning, operation, decommissioning) for all interface permutations and properly documented?		
	38	Have the residual risk and uncertainty been estimated and properly documented?		
	39	Has the reliability study been updated and properly documented?		
System Integration Stage	40	Has the design risk assessment (e.g., FMECA, HAZOP) considering full system interfaces been updated and properly documented?		
	41	Have all other technical risks been identified/addressed and properly documented?		
	42	Has the technology been deployed into a full prototype and fully integrated with the intended system?		
	43	Has the function/performance when connected/integrated into a wider system been fully tested?		
	44	Have all mechanical, hydraulic, optical, electronic, software, etc. and human interfaces been fully addressed and documented?		
	45	Have all system integration requirements been confirmed?		
	46	Has installation/hook-up/testing/commissioning with a wider system been completed as per specifications?		
	47	Is there a data collection system in place to document performance and reliability?		
	48	Has a detailed in-service inspection/monitoring/sampling plan been defined and properly documented?		
	49	Can inspection/monitoring/sampling functionality be validated?		
Operational Stage	50	Has the technology demonstrated acceptable reliability and availability in the targeted operating environment?		
	51	Has the in-field service monitoring, sampling, and inspection plan been successfully implemented?		
	52	Has reliability and integrity performance data been properly collected, analyzed, and documented?		
	53	Have any underperforming components of the technology been identified?		
	54	If so, then has there been any reliability improvements for failed or underperforming components?		

Qualification Stage	*Item #*	*Question*	*Yes/No/NA*	*Evidence to support?*
Operational Stage (continued)	55	Has there been any performance feedback from projects or suppliers?		
	56	Have any unexpected aspects (e.g., interdependencies or influences on performance) or safety concerns been observed?		
	57	Has the technology been reliable for at least one survey (or maintenance or planned replacement) cycle or agreed upon time period as indicated in the SRDD or in-service inspection plan (ISIP)?		
	58	Has the design risk assessment (e.g., FMECA) been updated with in-service performance data?		
	59	Has the system reliability assessment been updated and properly documented?		

APPENDIX 4 New Technology Qualification Plan (NTQP) Template

1 Introduction

The New Technology Qualification Plan (NTQP) should be a high level document that tracks the maturity level and status of qualification activities. These activities help verify and validate the new technology's ability to qualify all desired NTQ stages. The document is not meant to be a collection of engineering reports, methodologies, test data, or plans. The NTQP is to be updated throughout qualification process.

The following sections provide a recommended template for submitting an NTQP as part of the new technology qualification process.

3 New Technology Qualification Plan (NTQP) Template

Executive Summary

1.0 Introduction

- Summarize the project objectives.
- Provide an overview of the new technology and its application.
- Describe current status of design and qualification activities.
- Provide key points of contact.

2.0 New Technology Screening and Stage Determination

2.1 System Requirements Overview

- Summarize defined system goals, functional and performance requirements (with reference to appropriate SRDD document(s)).

2.2 New Technology Screening

- Summarize the new technology screening results.

2.3 New Technology Stage Determination

- Summarize the results of the new technology stage determination process.

3.0 New Technology Qualification Activities

- For each new technology item being qualified, list all qualification activities including the following details for each activity
  - Summarize the qualification activity (scope, objective and method)
  - Performance Requirement and its source.
  - Identify the stage in which this qualification activity was determined.
  - Provide reference to appropriate engineering evaluation report or risk assessment report (include corresponding hazard register nodes) from which this activity was determined.
  - Scheduled Timelines (start/finish).

- Provide reference to appropriate engineering evaluation or risk assessment reports that documents the results of the qualification activity.
- Comments from the Client & ABS

4.0 References

Appendices:

Appendix 1 Summary of Previous Qualification Activities

List all previously completed qualification activities prior to NTQ process with references to appropriate reports.

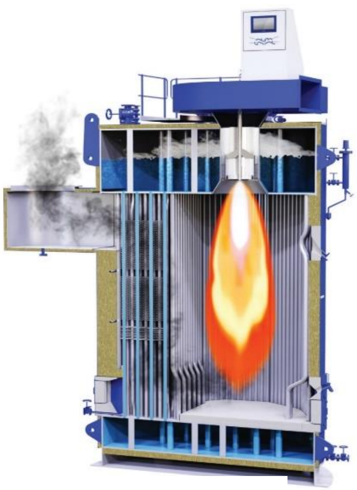
Emissions Evaluation of a Large Capacity Auxiliary Boiler on a Modern Tanker

Draft Final Report

Prepared for

California Air Resources Board
CARB

March, 2020



Source Alpha Laval

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Disclaimer

The statements and conclusions in this report are those of the contractor and not necessarily those of the California Air Resources Board (CARB). The mention of commercial products, their source, or their use in connection with material reported herein is not to be construed as actual or implied endorsement of such products.

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Acronyms and Abbreviations

σ…………………… ....standard deviation
BC ....black carbon
CARB..California Air Resources Board
CE-CERT..College of Engineering-Center for Environmental Research and Technology (University of California, Riverside)
CFR ....Code of Federal Regulations
cm/s ....centimeters per second
CO ....carbon monoxide
COV ....coefficient of variation
CO_2..carbon dioxide
DF ....dilution factor
eBC ....equivalent black carbon
EC ....elemental carbon defined by thermal optical methods
EPA ....United States Environmental Protection Agency
IMO..International Maritime Organization
ISO ....International Organization for Standardization
kPa..kilo Pascal
lpm ....liters per minute
ULSFO..low sulfur heavy fuel oil
MGO ....marine gas oil
MFC ....mass flow controller
ms...milliseconds
MSS..Micro Soot Sensor
NIOSH ....National Institute of Occupational Safety and Health 5040 protocol
NIST...National Institute for Standards and Technology
NO_x ....nitrogen oxides
OC ....organic carbon defined by thermal optical methods
o.d...outer diameter
OEM...original equipment manufacturer
PM..particulate matter
$PM_{2.5}$ ....fine particles less than 2.5 µm (50% cut diameter)
PTFE ....polytetrafluoroethylene
QC ....quality control
SRL ....sample reporting limit
scfm..standard cubic feet per minute
S ....sulfur
SO_2 ....sulfur dioxide
SO_x ....sulfur oxide
UCR ....University of California at Riverside
Stdev. ....Standard deviation one sigma

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Executive Summary

Introduction: More than ten years have passed since emissions were measured from the large auxiliary boiler on a Suezmax tanker while it unloaded about one million barrels of crude. Modern vessels use newer boiler designs so it is of interest to measure their emissions. The Alpha Laval unit is an Aalborg OL large capacity auxiliary boiler with a super heater, representative of a modern boiler for tankers. Alpha Laval is a market share leader so data from this unit should provide an important perspective on the emissions from widely-used tanker boilers with the latest technology advances. Further, ships operating within California waters now use low-sulfur distillate fuels so results from this test will show the combined effects of a modern boiler design and the cleaner California fuels.

Methods: The test methods utilized International Organization for Standardization (ISO) 8178-4 sampling protocols. The boiler was evaluated at one load representative of normal operation. The emissions measured were regulated gaseous, speciated hydrocarbons C2-C12, aldehydes and ketones, metals, particulate matter mass less 2.5 um ($PM_{2.5}$), and PM composition which included elemental and organic carbon (EC and OC) PM. Other methods and practices, sampling dilution, and calculations such as dry to wet correction, followed ISO and Code of Federal Regulations (CFR) recommendations.

***Objectives*:** The primary aim of this work is to study the in-use emissions from a modern tanker boiler utilizing California approved MGO low sulfur fuel.

Results gaseous: The boiler carbon dioxide (CO_2) emissions were 3026 g/kg-fuel which is similar to previous testing of a modern auxiliary boiler on a container vessel suggesting the results are representative of a properly operated boiler. The nitrogen oxide (NO_x) emissions averaged 2.86 ± 0.18, carbon monoxide (CO) 0.06 ± 0.064, and sulfur dioxide (SO_2) 0.94 g/kg-fuel. The NO_x emissions were slightly higher, with-in 50%, to previous testing of a modern container vessel auxiliary boiler tested on low sulfur MGO and ULSFO fuels, but over two times lower (2.2) than the emissions on a tanker vessel auxiliary boiler tested on high sulfur HFO fuel.

Results PM: The $PM_{2.5}$ emissions were 0.022 ± 0.004 g/kg-fuel and were slightly lower compared to previous testing of a modern auxiliary boiler tested on low sulfur MGO and ultra-low sulfur fuel oil (ULSFO) fuels, but over 100 times lower (131) than the PM emissions on a boiler tested on high sulfur heavy fuel oil (HFO). The equivalent black carbon (eBC) emissions were 0.0012±0.0004 g/kg-fuel and were about the same for a previous modern boiler tested, but about 120 times lower than the EC emission reported for an older boiler tested on a tanker. The PM compostion is mostly organic (68%) and about 1.5% elemental carbon.

Results Toxics: The boiler emissions for Formaldehyde, Acetaldehyde and Acrolein were 0.401, 0.376, and 1.749 mg/kg-fuel. These results compare well with the modern boiler operating on MGO fuel test from a container vessel. Modern boilers operating on MGO fuels appear to have lower Acetaldehyde and Acetone emissions compared to older boiler tested on HFO fuels. The PAMS measurements were at the detection limit of the measurement method and thus, could not be compared properly to the previous testing on an older boiler tested on a high sulfur HFO fuel. These results are useful for updating the model with “less than” type of values. The metals emissions were… Waiting on data.

Summary: Modern boilers operating on MGO fuels have lower NO_x and total PM mass compared to older boilers operating on high sulfur fuels. These results show the benefit of modern boilers operating on low sulfur MGO fuels.

1 Background

1.1 Marine Boiler Emissions

More than ten years have passed since emissions were measured from a large boiler on a Suezmax tanker while it unloaded about one million barrels of crude. Results of that project were peer reviewed and published (Agrawal et al 2008). The results were an all-inclusive set of regulated and nonregulated emissions factors for criteria pollutants (carbon monoxide (CO), nitrogen oxides (NO_x), sulfur oxides (SO_x), and particulate matter (PM) mass), a greenhouse gas (carbon dioxide (CO_2)), speciated hydrocarbons needed for human health risk assessments, and a detailed analysis of the PM into its primary constituents (ions, elements, organic, and elemental carbon (EC and OC)). Details on the heavy fuel oil (HFO) and boiler design are found in the publication.

Modern vessels use newer boiler designs so it is of interest to measure their emissions. The boiler tested in this project was an Alpha Laval Aalborg OL large capacity auxiliary boiler with a super heater. Alpha Laval is a market share leader so data from this unit should provide an important perspective on the emissions from widely-used auxiliary boilers with the latest technology advances. Further ships operating within California waters now use low-sulfur distillate fuels so results from this test will show the combined effects of a modern boiler design and the cleaner California fuels.

Marine boilers, called auxiliary boilers, are used for supplying steam and hot water for non-propulsion uses such as fuel heating, galley, cabin space heating, and to drive steam turbines on tankers that offload petroleum crude oil in ports. Boilers can range in size where for container vessels and bulk carriers they tend to be smaller than the ones on a tanker vessel. The boiler tested in this research had a fuel consumption and exhaust flow rate ten times larger than the container vessel auxiliary boiler. Thus, tanker boiler emissions are a of importance to the California Air Resources Board (CARB) to estimate their environmental impacts.

1.2 Objective

The objective of this research is to evaluate the emissions from a modern auxiliary boiler on a tanker ship while it offloads fuel with-in a port in Northern California where the main engine is off. The testing followed the same protocol as used in the earlier study with one exception, the method used for measuring the nonregulated air toxics. Following the same protocol of the earlier study will allow a direct comparison of emissions and provide information on the changes in emissions over time.

2 Approach

This section outlines the in-use emissions testing approach for the modern boiler on a xx-class tanker vessel. This section describes the test article (boiler, fuel, and load point), sampling approach (sample location, sample discussions, and test protocol), measurements (gaseous and PM measurement methods, toxic sampling approach), calculations (exhaust flow determination), and a discussion of the assumptions used in the data analysis. The test article sections cover design details of the boiler operation. The sampling approach describes where the samples were collected from the exhaust, any impact this location may have on the measurement, and the test protocol. The measurements section describes the measurement methods for the gaseous, PM (mass and composition), and toxics samples. The corrections and assumption section provide a discussion on the data and analysis used in this report.

2.1 Test article

The boiler, fuel, and test matrix are described in this section.

2.1.1 Boiler

The boiler tested is an Alpha Laval's large capacity auxiliary boiler (2xAalborg OL 50,000 kg/h) installed on a tanker vessel. This boiler design includes a super heater unit, 2xAalborg XW-S with a steam rating of 50,000kg/h. The boiler operation is automatically controlled. A diagram is presented in Figure 2-1 and the OL model specifications are provided in Table 2-1.

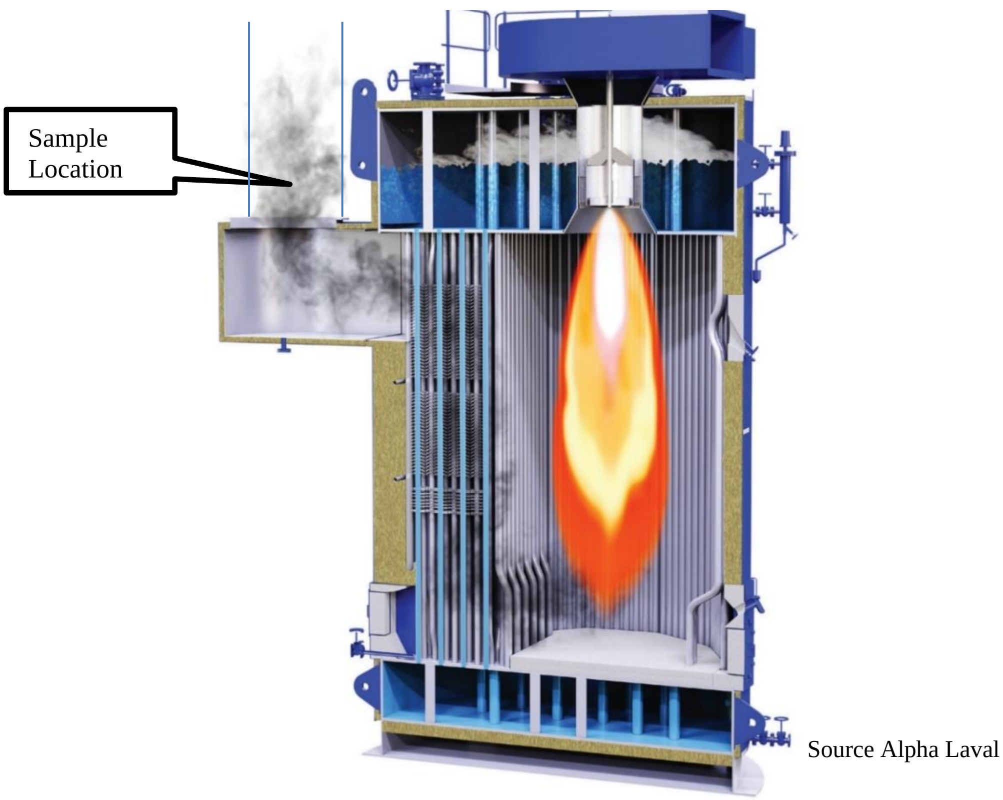


Figure 2-1 Design diagram of large frame boiler series

The test unit represents one of the larger boilers made by Alpha Laval. According to Alpha Laval's brochure, the unit tested, rated at 50,000kg/h steam capacity, is a boiler near the highest level of steam production that is commercially offered. This suggests the boiler emissions will be of interest to regulators since it is one of the higher emission rate boilers in mass/time for this type of tanker activity.

Table 2-1 List of Alpha Laval large frame boilers, 50,000 kg/h tested)

Steam capacity	Design pressure	Thermal output at 100% MCR	Height K (incl. retraction of burner lance)	Diameter D (incl. insulation)	Hight H	Width B	Boiler dry weight*)	Boiler operation weight
kg/h	bar(g)	kW	mm	mm	mm	mm	ton	ton
12,500	9	8,800	8,610	2,670	6,310	4,070	16.4	23.3
16,000	9	11,300	8,810	3,070	6,310	4,320	20.5	29.6
20,000	9 / 18	14,100	8,940	3,220	6,460	4,595	24.5 / 28.5	35.5 / 39.2
25,000	18	17,600	10,050	3,320	7,310	4,800	30.3	41.5
30,000	18	21,200	10,360	3,570	7,510	5,200	35.1	48.2
35,000	18	24,700	10,300	3,870	7,360	5,600	40.4	55.8
40,000	18	28,200	10,880	3,870	7,760	5,625	42.6	58.4
45,000	18	31,800	10,870	4,270	7,710	6,125	49.3	68.6
55,000	18	38,800	11,050	4,520	7,760	6,600	56.6	78.5

Source Alpha Laval

2.1.2 Test fuels

A standard low sulfur marine gas oil (MGO) fuel was used during this testing. The fuel complies with the CARB's Fuel Rule for Ocean-Going Vessels, which allows either an MGO or a marine diesel oil (MDO) at or below 0.1% sulfur (S). A fuel sample was taken, and the results show the fuel sulfur was less than 0.1% (S = 0.045% following D4294 and X-ray methods, see Appendix D). The test fuel had a carbon weight fraction of 0.8682 and a hydrogen weight fraction of 0.1286, See Appendix D for analysis report.

2.1.3 Test matrix

Typically, a test matrix includes a range of loads, but boilers operation tends to be constant load with periods of on/off control to maintain steam pressure. The fuel oil flow in the boiler is relatively constant while the boiler produces the highest steam rate for the turbine pump needs during land-based transfers (as tested during this project). As the land-based tanks reach their capacity, the boiler fuel rate slows slightly to accommodate a switch-over in the storage tanks.

Figure 2-2 shows the steam rate and fuel consumption for a different, but similarly sized auxiliary marine boiler made by Mitsubishi. The 50,000 kg/h Mitsubishi steam rate boiler shows a maximum fuel oil consumption of 3,787 kg/hr. If we assume the maximum consumption between manufacturers is similar, we can estimate the load on the boiler tested as a percentage of maximum. The measured fuel consumption during this testing was 2,400 kg/hr, suggesting the boiler was operated at an estimated 65% of its maximum design load.

The crew suggested the boiler could be operated at this "65%" state and also at a slightly lower steam rate. As such, there was a desire to test these two load points, but due to time limitations, however, we only had time to test the higher 65% load condition and not the lower load condition. The data in this report represents the 65% load case at a fuel consumption rate of 2,400 kg/hr.

Boiler type		MAC -20B	MAC -25B	MAC -30B	MAC -35B	MAC -40B	MAC -45B	MAC -50B	MAC -55B
Evaporation	kg/h	~ 20,000	~ 25,000	~ 30,000	~ 35,000	~ 40,000	~ 45,000	~ 50,000	~ 55,000
Boiler design pressure	MPa	1.77							
Working steam pressure	MPa	1.57							
Steam temperature	°C	*Saturated temperature to 280							
Boiler efficiency (LHV base)	%	80.5				82.5			
Feed water temperature	°C	60							
Air temperature	°C	38							
Number of burners	-	1							
Fuel oil consumption	kg/h	1,552	1,940	2,328	2,716	3,029	3,407	3,787	4,165

Figure 2-2 Heat loads and fuel rates for other boilers

(source Mitsubishi Heavy Ind.)[1]

2.2 Sampling approach

This section provides a discussion of the sample locations (PM representativeness and accessibility), and the test protocol (methods of sampling).

2.2.1 Sample locations

Sampling utilized UCR's partial dilution tunnel system, as outlined in ISO 8178-1, with a direct connection to the exhaust sample, see Appendix A for more details. Several points of access to the exhaust were identified during a site visit months before the testing campaign. The recommended location identified was near the top of the boiler stack where a cross-plume smoke meter was installed. The plume smoke meter was disconnected during testing and reinstalled afterwards, see Figure 2-4 and Figure 2-5. This location is free of bends and is a good location for sampling.

Figure 2-3 Platform space available for equipment (smoke meter shown)

[1] https://www.mhi-mme.com/products/boilerturbine/auxiliary_boilers.html#tab03_2 Auxiliary boiler project specifications.

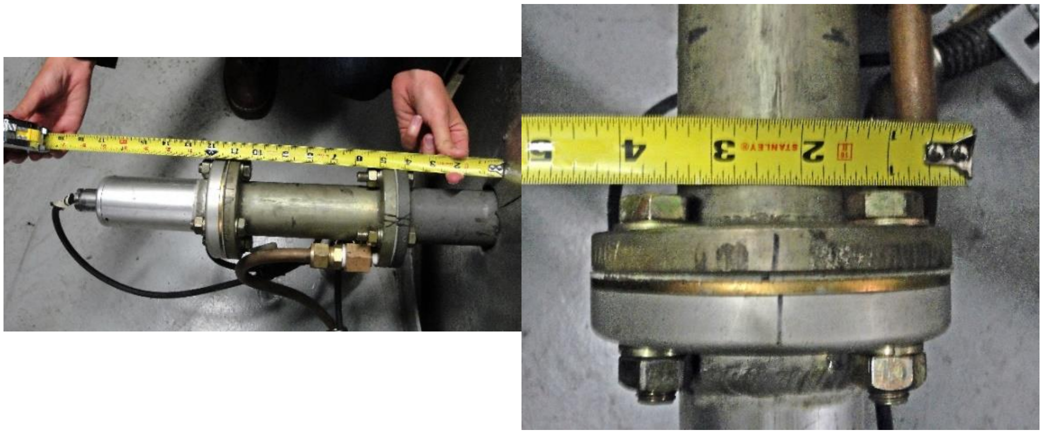


Figure 2-4 Dimensions for probe length and flange size

There were no sample ports prior to the heat exchanging surfaces where one can measure the boiler emissions directly, as can be seen by the boiler layout shown in Figure 2-1. UCR, therefore, utilized the cross-plume smoke meter sample location as the only practical sample location. The length of the sample probe needed to be 12 inches to access a well-mixed exhaust sample using good engineering judgment (which is 10% inside the wall of the exhaust stack where the flow is well mixed). The dimensions show the probe design should be 12 inches, see Figure 2-4 and Figure 2-5.

The dilution tunnel length with the installed cyclone was interfering with the vessel stack to the left in the figure shown below, see Figure 2-5. The tunnel would fit with the cyclone removed. Since this was the only suitable sample location the cyclone had to be removed in order to collect any samples from the boiler. The impact of this decision is provided in Section 2.5.

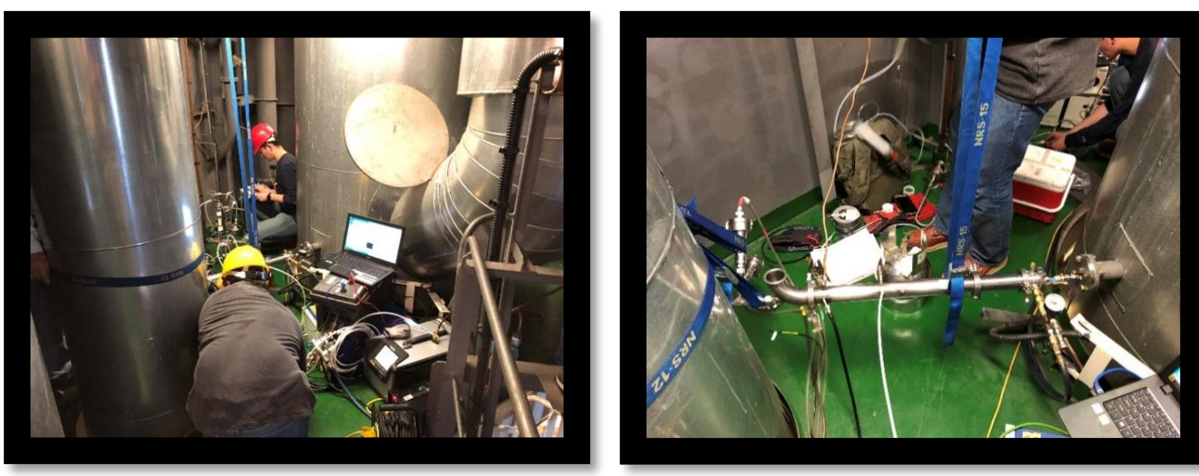
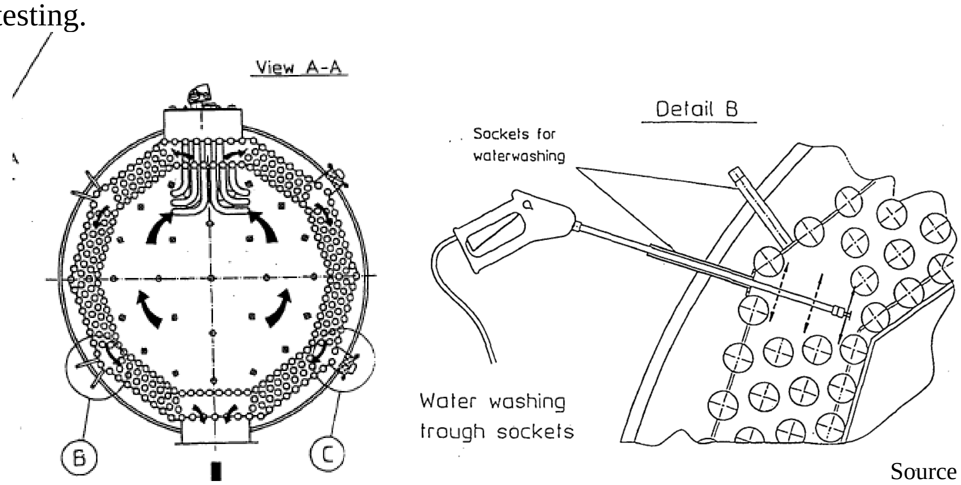


Figure 2-5 Boiler tunnel setup: thermopile probe removed for sampling

2.2.2 PM fouling discussion

Sampling after a heat exchanging surfaces, like a boiler, can be a source for PM adsorption and desorption because these surfaces heat and cool in the presence of PM where thermophoretic loss/accumulation (Hind 2nd Edition 1999) can be significant. During boiler-on conditions, the hot boiler exhaust gas heats the cool boiler tubes and PM can adsorb on the surfaces. As the tube surfaces can get hot, PM may start to desorb. Then, during periods of boiler-off condition (reduced water heating), the heat exchanger surfaces will cool until the next cycle. The adsorption and desorption of PM on a boiler surface can be described by thermophoretic loss models in Hind (2nd Edition 1999). When PM is adsorbed onto the surface, stack PM emission factors can be underestimated over short periods of time (measured in hours). This suggests the location for the sample probe is important to try and be before the surfaces and the condition of the boiler cleaning is important.

The boiler heat exchanger surfaces do include cleaning recommendations of the heat exchanger surfaces. According to the Aalborg manual, the boiler cleaning is performed by routine air blasts and occasional water blasts. The rate of cleaning varies with the quality of the fuel and the indications from the installed smoke meter. The water blasts are performed when boiler performance declines. There are several access ports for these water blast ports, see Figure 2-6. According to discussions with the crew the boiler was in a clean state, thus suitable for our emission testing.



Source Alpha Laval

Figure 2-6 Cleaning setup for an Aalborg boiler

2.2.3 Test protocol

The boiler load was operated for more than 30 minutes at the highest power possible to warm the engine and stabilize emissions. Repeats of the same load are performed prior to changing loads (i.e. mode 1, 1, 1 change load, mode 2, 2, 2 load change…). Based on experience testing OGVs, repeating test points with this approach is needed to manage the time it takes between different load points and to prevent issues when navigating in areas with speed restriction. For this testing, however, only one load point was performed so there were not conditions to wait for. In general, at each steady state test mode, the protocol requires the following:

- Allow the gaseous emissions to stabilize before measurement at each test mode (minimum 10 minutes as per ISO). This was possible on the ME and AE tests, but due to strict time constraints on the boiler this guide was not followed, but emissions were stable regardless.
- Measure gaseous and PM concentrations for at least 3 minutes and no longer than 30 minutes (such that approximately 500µg of filter mass is collected at a minimum dilution ratio of 4:1). For the boiler tests the filter weights averaged 100 ug even with long sampling times of 40 minutes.

- Measure direct stack exhaust mass flow rate via EPA Method 2. Additionally, UCR recorded the fuel consumption of the boiler using discussions with vessel crew.
- Calculate emission factors from the measured pollutant concentration data and calculated mass flow rates.

2.3 Measurements

Like other marine tests, the measurement of exhaust concentrations followed the CARB[2] and IMO[3] protocols, see Appendix A for an in-depth description of UCR's marine sampling system. A dilution tunnel is connected directly to the exhaust stack without the need for a transfer line. The flow in the dilution system eliminates water condensation in the dilution tunnel and sampling systems and maintains the temperature of the diluted exhaust gas at <52°C before the filters.

An overview of UCR's partial dilution system is shown in Figure 2-7. Raw exhaust gas is transferred from the exhaust pipe (EP) through a sampling probe (SP) and the transfer tube (TT) to a dilution tunnel (DT) due to the negative pressure created by the venturi (VN) in DT. The gas flow rate through the TT depends on the momentum exchange at the venturi zone and is therefore affected by the absolute temperature of the gas at the exit of TT. UCR's marine testing is directly connected to the stack so to minimize PM losses. The dilution ratio targeted and verified for this testing project was 10:1 and the actual dilution ratio was 7:1.

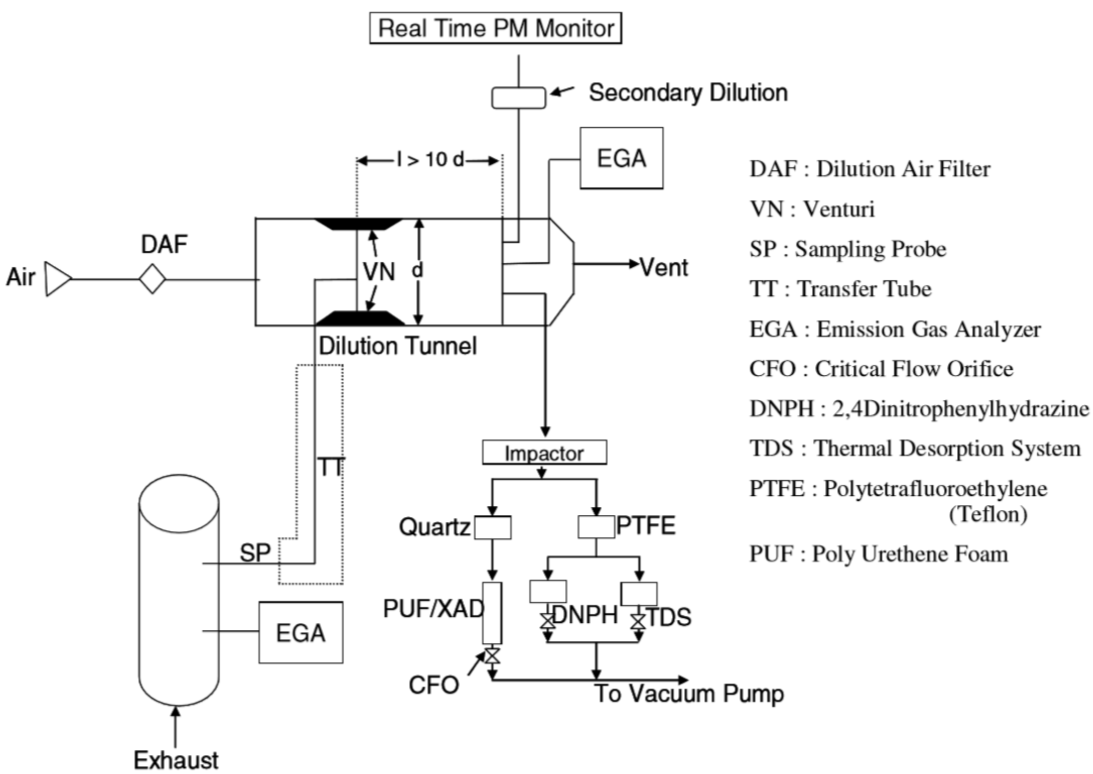


Figure 2-7 Sample schematic utilized

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[2] California Air Resources Board, *Recommended Emissions Testing Guidelines for Ocean-going Vessels*, https://www.arb.ca.gov/ports/marinevess/documents/emissiontest/OGV%20Test%20Guidelines.pdf, (2012)

[3] ISO 8178-1 Reciprocating internal combustion engines - Exhaust emission measurement - Part 1: *Test-bed measurement of gaseous and particulate exhaust emissions*

[1] For this testing the TDS and PUF were not utilized and Suma canisters were collected from the secondary dilution system. Additionally, raw Suma canister grab samples were collected and analyzed.

ISO cautions that the advantages of partial flow dilution systems can be a source of sampling problems such as: losing particulates in the transfer tube, failing to take a representative sample from the engine exhaust and inaccurately determining the dilution ratio. UCR includes standard methods for each marine application to ensure these concerns are managed properly.

2.3.1 Gaseous and PM emissions

Best recommended practices for OGV exhaust gas measurements follow 40 CFR Part 1065 for PM measurements with specific details following ISO 8178-1 for dilution and exhaust gas sampling. The measurement approach is summarized here, with more details available in Appendix A.

Gaseous: The concentrations of gases in the diluted exhaust tunnel was measured with a Horiba PG-350. Nitrogen Oxides (NO_x) utilize a heated chemiluminescence detector (HCLD), carbon monoxide (CO) and sulfur dioxide (SO_2) utilize non-dispersive infrared absorption (NDIR) with cross flow modulation, and oxygen (O_2) utilize a zirconium oxide sensor. Major features of the PG-350 include a built-in sample conditioning system (5 deg C) with sample pumps, data storage on a flash drive, integrated mist and particle filters, and a thermoelectric cooler. The performance of the PG-350 was tested and verified under the U.S. EPA and ETV programs.

Gaseous concentrations were measured directly from the dilution tunnel and from raw exhaust during dilution ratio verification. Dry-to-wet corrections were performed using calculated water concentration from the exhaust and the dilution tunnel.

Table 2-2 Summary of Emissions Measured by UCR

Species Sampled			
NDIR CO	NDIR CO_2	CLD NO_x	Photoacoustic eBC
NDIR SO_2	Total **$PM_{2.5}$** Gravimetric method	PM EC/OC NIOSH method	

Particulate Matter (PM) mass: UCR's PM measurements use a partial flow dilution system that was developed based on the ISO 8178-1 protocol, detailed information is provided in Appendix A. Total PM mass less than 2.5 um diameter ($PM_{2.5}$) is measured from the diluted exhaust gas according to the Code of Federal Regulations (CFR) 40 CFR Part 1065. UCR utilizes 47 mm 2um pore Teflon filters (Whatman Teflo) weighed offline with UCR's UPX2 Mettler Toledo micro balance (0.1 ug resolution) in a temperature, humidity, and particle-controlled environment. The microbalance is operated following the weighing procedures of the CFR. Before and after collection, the filters are conditioned for a minimum of 24 hours in an environmentally controlled room (RH = 45%, T = 21 C, 9.5 C dew point) and weighed daily until two consecutive weight measurements were within 3µg.

PM Composition: The project measured PM composition which comprises elemental carbon (EC) and organic carbon (OC). OC/EC analysis was performed on samples collected on 2500 QAT-UP Tissuquartz Pall (Ann Arbor, MI) 47 mm filters that are preconditioned at 600°C for 5 h. A 1.5 cm2 punch is cut out from the quartz filter and analyzed with a Sunset Laboratory (Forest Grove, OR) Thermal/Optical Carbon Aerosol Analyzer according to the NIOSH 5040 reference method. The PM composition filters were sampled from UCR dilution tunnel at a targeted flow rate of 15 slpm.

Metals: The metal analysis has not been performed at this time. It will be performed on the Teflon PM samples using X-Ray Fluorescence (XRF) from an offline analytical method. The filters were first weighed then will be sent out for XRF analysis. The method offers analysis of elements (Na through Pb) represented by 38 elements. XRF is an EPA approved, non-destructive analytical method (IO-3.3) wherein a filter is bombarded with X-ray energy. The subsequent excitement of electrons can be measured when the electrons fall back to their valence state, releasing energy in the process. Each element has a "fingerprint" of energy discharges which are measured to determine the quantity of each element.

Equivalent black carbon (eBC). Bond et al (2013) provided a definition of black carbon (BC) measurement methods as they relate to characterizing climate impacts. The photoacoustic measurement method is considered to be an equivalent BC method (denoted as eBC), the NIOSH thermal optical method is an apparent elemental carbon measure of BC (denoted as EC), single particle soot photometers such as the laser-induced incandescence measure the refractory nature of BC (denoted as rBC), and particle soot absorption photometers such as the Aethalometer and MAAP instruments measure the equivalent BC (denoted as eBC). The instrument utilized for BC measurements in this study was UCR's in-house photoacoustic real-time analyzer (AVL MSS-483) which represents the eBC measurement method as defined by Bond and is utilized here for consistency. The photoacoustic measurement method is a reliable and robust measurement for quantifying marine BC where the PM fractions vary significantly and have been shown to impact the EC measurement method (Bond et al 2013 and Johnson et al 2016). The photoacoustic measurement was sampled from the same dilution tunnel used for the gravimetric and NIOSH filter samples.

2.3.2 Toxics

CARB utilizes speciation estimates from boiler emissions that are used in the emission inventory and air quality models. These models are lacking toxic data from marine boilers. As such, additional toxic samples were utilized for the boiler tests. These included aldehydes and ketones, speciated hydrocarbons, and metals. All the toxic samples were collected from the dilution tunnel as shown in Figure 2-7. Additionally, two speciated hydrocarbon samplers were collected directly from the raw stack to improve measurement sensitivity.

Total Gaseous Non-Methane Organics (TGNMO) concentrations are often measured using a total hydrocarbon analyzer with a field ionization detector (FID). However, these devices have a flame and are not usually allowed on a tanker vessel. For this project diluted exhaust samples were collected in SUMMA® canisters, equipped with flow controllers and subsequently analyzed for TGNMO at Atmospheric Analysis and Consulting (AAC) an off-site laboratory.

PAMS AAC also analyzed the SUMMA canisters for VOC's and BTX to process the total PAMS impact of the speciated HCs. They used the TO-12/PAMS method which provides the data for VOCs including light toxics (BTX and butadiene) and the PAMS profile needed for air quality modeling. With this method, the analysis provides concentrations of the following hydrocarbons.

Ethylene
Acetylene
Ethane
Propylene
Propane
Isobutane
1-Butane
N-Butane
Trans-2-Butene
Cis-2-Butene
Isopentane
1-Pentane
N-Pentane
Isoprene
Trans-2-Pentene
Cis-2-Pentene
2,2-Dimbutane
Cyclopentane
2,3-Dimenthylbutane
2-Methylpentane
3-Methylpentane
1-Hexane
N-Hexane
Methylcyclopentane
2,4-Dimethylpentane
Benzene
Cyclohexane
2-Methylhexane
2,3-Dimethylpentane
3-Methylhexane
2,2,4-Trimethylpentane
N-Heptane
Methylcyclohexane
2,3,4-Trimethylpentane
Toluene
2-Methylheptane
3-Methylheptane
N-Octane
Ethylbenzene
M/P-Xylenes
Styrene
O-Xylene
N-Nonane
Isopropylbenzene
N-Propylbenzene
M-Ethyltoluene
P-Ethyltoluene
1,3,5-Trimethylbenzene
O-Ethyltoluene
1,2,4-Trimethylbenzene
N-Decane
1,2,3-Trimethylbenzene
M-Diethylbenzene
P-Diethylbenzene
N-Undecane
N-Dodecane

Note in the earlier tanker measurement project, VOC adsorbed molecules starting about C_4 (butadiene) through C_{12} were collected on a multi-bed carbon bed composed of molecular sieve, activated charcoal, and carbotrap resin. The VOC included toxics such as 1,3 butadiene; benzene; toluene; ethylbenzene and xylenes. This method was not used during this testing campaign.

Aldehydes and ketones: Carbonyls (aldehydes and ketones) were collected on 2,4-dinitrophenylhydrazine (DNPH) coated silica cartridges (Waters Corp., Milford, MA) behind the Teflon filter. A critical flow orifice was used to control the 1.0 LPM flow through the cartridge. Sampled cartridges were sealed and stored at a cold temperature and later extracted using 5 mL of acetonitrile with the liquid then injected into Agilent 1100 series high performance liquid chromatograph (HPLC) equipped with a diode array detector. The HPLC column was similar to a 5µm Deltabond AK resolution (200cm x 4.6mm ID) with upstream guard column. The HPLC sample injection, and operating conditions are set up according to the specifications of the SAE 930142 HP protocol (Siegl, W et al 1993). The DNPH samples were collected from the dilution tunnel. Due to time limitations and sample difficulties only one valid sample was collected.

Metals: The metal analysis was performed on the Teflon PM samples using X-Ray Fluorescence (XRF) from an offline analytical method utilizing the same Teflon filters used to determine the

$PM_{2.5}$ mass. The filters were first weighed then sent out for XRF analysis. The method offers analysis of elements (Na through Pb) represented by 38 elements. XRF is an EPA approved, non-destructive analytical method (IO-3.3) wherein a filter is bombarded with X-ray energy. The subsequent excitement of electrons can be measured when the electrons fall back to their valence state, releasing energy in the process. Each element has a "fingerprint" of energy discharges which are measured to determine the quantity of each element.

2.3.3 Exhaust flow

The calculated emission factor requires the measurement of the engines exhaust flow rate. The exhaust gas flow can be determined by the following methods:

1. Direct Measurement Method (**utilized**)
2. Carbon Balance Method (not available, lacking measured fuel consumption**)**
3. Air and Fuel Measurement Method (not available)
4. Air Pump method (not possible on boilers only engines)

Although there are four accepted methods for measuring flow rate, the direct measurement approach was most suitable for boiler testing. Direct exhaust flow measurement is complex and requires long straight sections which is not typically available on OGVs exhaust systems. Thus, direct measurement has not been a preferred method at UCR for engine exhaust flow, where fuel flow measurement has been utilized. For this boiler, there was a suitable straight section for good exhaust flow direct measurement. Thus, direct flow measurement (#1) was utilized for accurate emissions calculations.

The direct measurement system utilized in this project was a type S Pitot tube is used to measure the differential pressure between the counter-flow (static pressure) and parallel-flow (dynamic pressure) directions. This method follows EPA Method 2, see Section 2.4.2 and Appendix E for details.

2.3.4 Boiler

The boiler output was not available for recording and only a single mode was utilized given the short time frame allowed on the vessel. The boiler was operated under normal usage conditions in a high load operation maintaining bulk fuel temperature. It is estimated based on the recorded fuel rate that the boiler load was around 65% of its total capacity.

2.4 Calculations

The calculations are described in this section.

2.4.1 Emission factors

The emissions were collected at the one mode in triplicate to allow for the determination of confidence intervals for the reported means. The triplicate measurements were performed by collecting three samples (i.e. triple or three repeated measurements) at each load point for all the species of interest (gaseous continuous and integrated PM samples). The result is based on the measured mass flow in the exhaust stack, the measured concentration of species, divided by the fuel rate calculated by the carbon balance method utilizing the MGO fuel as specified in Section 2.1.2. An overall single emission factor representing the boiler was determined by dividing the integrated mass of emissions (g/hr) by the integrated fuel rate (kg-fuel/hr) to get an emission factor of g/kg-fuel for each species presented.

2.4.2 Exhaust flow

The exhaust flow calculation follows EPA Method 2 which utilizes a type S Pitot tube is used to measure the differential pressure between the counter-flow (static pressure) and parallel-flow (dynamic pressure) directions, see Figure 2-8. Velocity is calculated using Bernoulli's principle, which states that the pressure in a stream of fluid is reduced as the speed of the flow is increased. The velocity calculation is based off of the temperature, molecular weight of the exhaust gas, static pressure, dynamic pressure, and relative humidity. Measurement of the differential pressure and temperature were repeated at the sampling site several times at different depths inside the duct, including the near side of the duct, in the middle of the duct, and the far side of the duct, see Appendix E for detailed exhaust flow calculation.

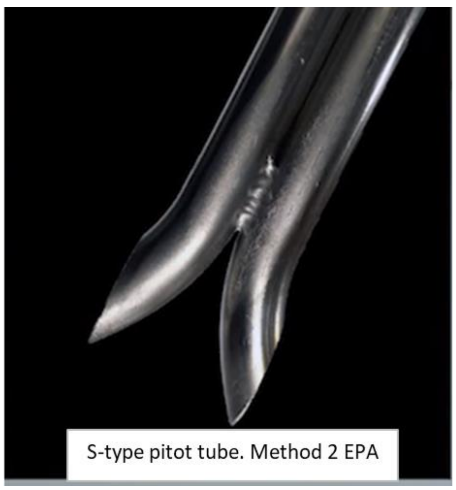

Figure 2-8 S-type pitot tube for EPA Method 2

2.5 Corrections and assumptions

Ship testing is very complex where space and time are limited, and setup is from instruments which were transported in boxes to the test site and setup. As such, it is expected not everything will go according to plan, but most data on ships is of value since it is hard to come by.

This section was added to discuss three issues that occurred while testing the boiler. These issues may impact the emissions where this section provides context to the quality of the reported data.

2.5.1 Emissions stability

There was a small stability issue that occurred at the start of sampling that may impact the gaseous emissions slightly and the eBC more significantly. The stability issue can be seen by the slight increase in CO_2 and NO_x concentration for the first hour of testing, see Figure 2-9 between 10:30 and 11:30 (note this was after 1-2 hours of boiler stabilizing). The change in NO_x concentration is small (1 ppm NO_x) and larger for CO_2 (1.5% CO_2), but the Test 1 MSS soot measurement (eBC) is five times higher than the steady state measured soot measurement of Test 2, see the grey trace in Figure 2-9. It is not clear what happened between 10:30 and 11:30, but it seems there was a slight change in fuel usage (CO_2 change) and unstable eBC emission (BC desorption, fueling, or other). There was also an impact in the PM filters as can be seen by the color of the filters, see Figure 2-10. The first filter, Test #1, was darker then Test #2 and #3 supporting what was visible with the real time MSS soot sensor. The overall PM filter mass, however, did not change significantly, as discussed in the next sub section.

Previous testing on a container vessel modern boiler showed that soot concentration (eBC method) was very stable and averaged about 0.01 mg/m3 during the 8 hours of sampling over three separate days. This would suggest the more representative eBC value is the one between 11:50 and 12:10 for test 1. As such, a re-analysis of the real time data was performed to collect the data for the stable time segment. A re-analysis of the gaseous emissions was also collected for this time period. The original sample durations are shown by orange circles and bars, the modified time segments are denoted by the green circles, see Figure 2-10. The results presented in this are based on the analysis during the green circles. The details of the original and modified data are provided in Appendix F.

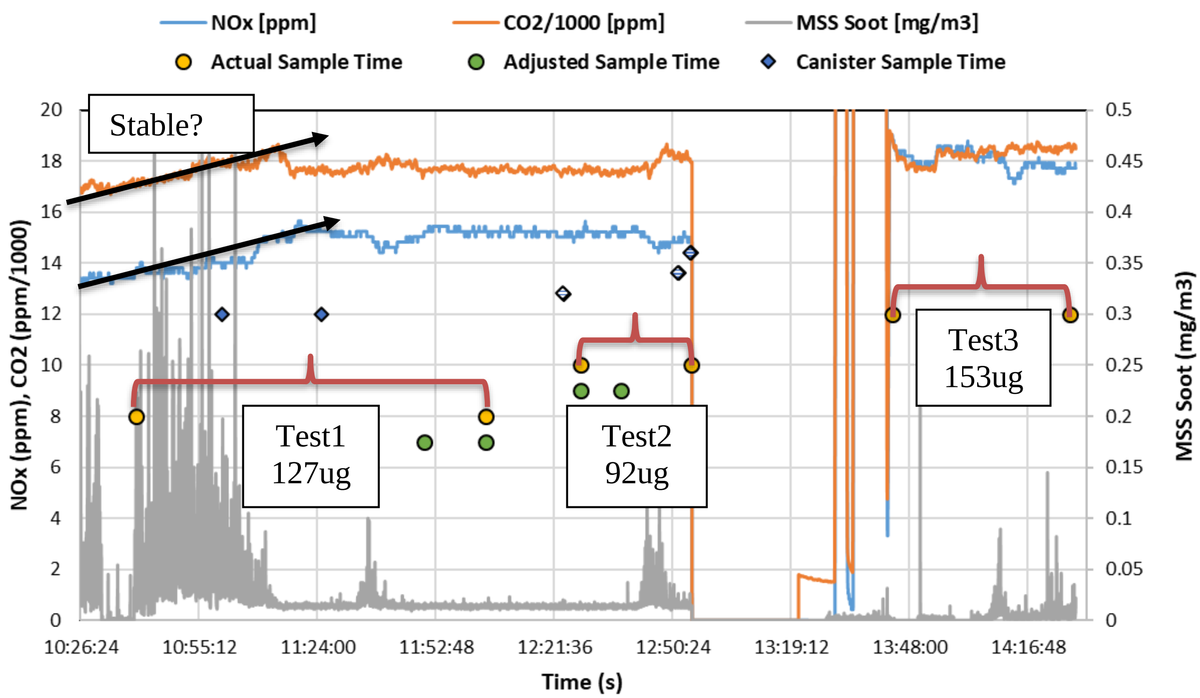

Figure 2-9 Real time emissions for tests 1, 2, and 3

[1] Orange circles are the original sample times for PM filters, The blue triangles are the stop and stop of the SUMA canisters, green are the revised sample averaging times for the eBC and gaseous emissions.

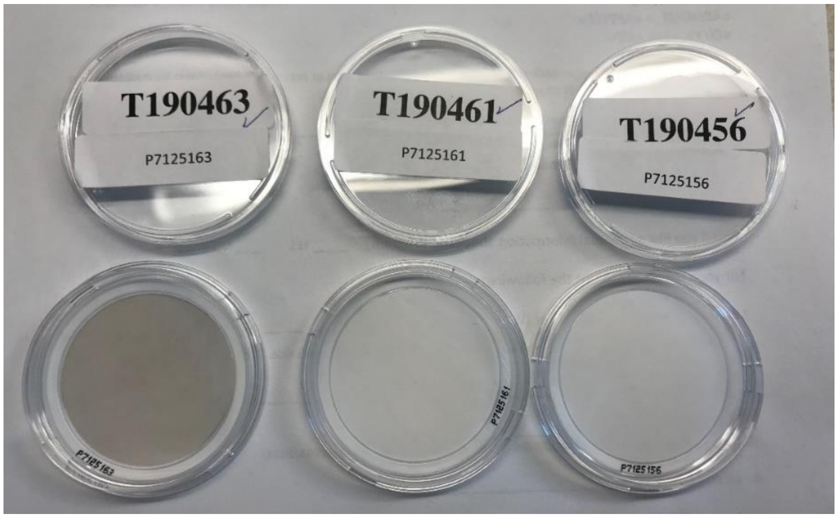

Figure 2-10 Sample filters Test 1, 2, and 3
[1] The filter weights were 127, 153, and 92 ug from left to right.

2.5.2 Filter spotting

During the dilution tunnel installation, the PM cyclone would not fit due to space limitations so it had to be removed, see discussion in Section 2.2.1. Cyclones were introduced into PM samplers to prevent collecting wall accumulated particles, debris in the exhaust, and other objects not emitting directly from the combustion process. Typically, a properly sampled PM filter would not show visible spotting. The spotting on these filters cannot be seen easily with-out some type of magnification, see Figure 2-10 vs Figure 2-11. The mass impact due to the spotting is believed to be small because less than 5% of the total mass is soot and the spotting would likely be soot based accumulation particles. Additionally, the PM mass for the darker filter is less than the PM mass for the other two filters showing that the color of the filter isn't what is causing the higher PM filter weights.

The results for the PM mass filters are presented "as is" where these values maybe be artificially high by 5% due to the filter # 1 eBC instability and the PM spotting. Also, these PM mass emission rates are similar to the recent boiler UCR tested on a container ship and these PM mass emission rates are much lower than a similar crude tanker tested in 2008 (Agrawal et al 2008), so the data is of value to report.

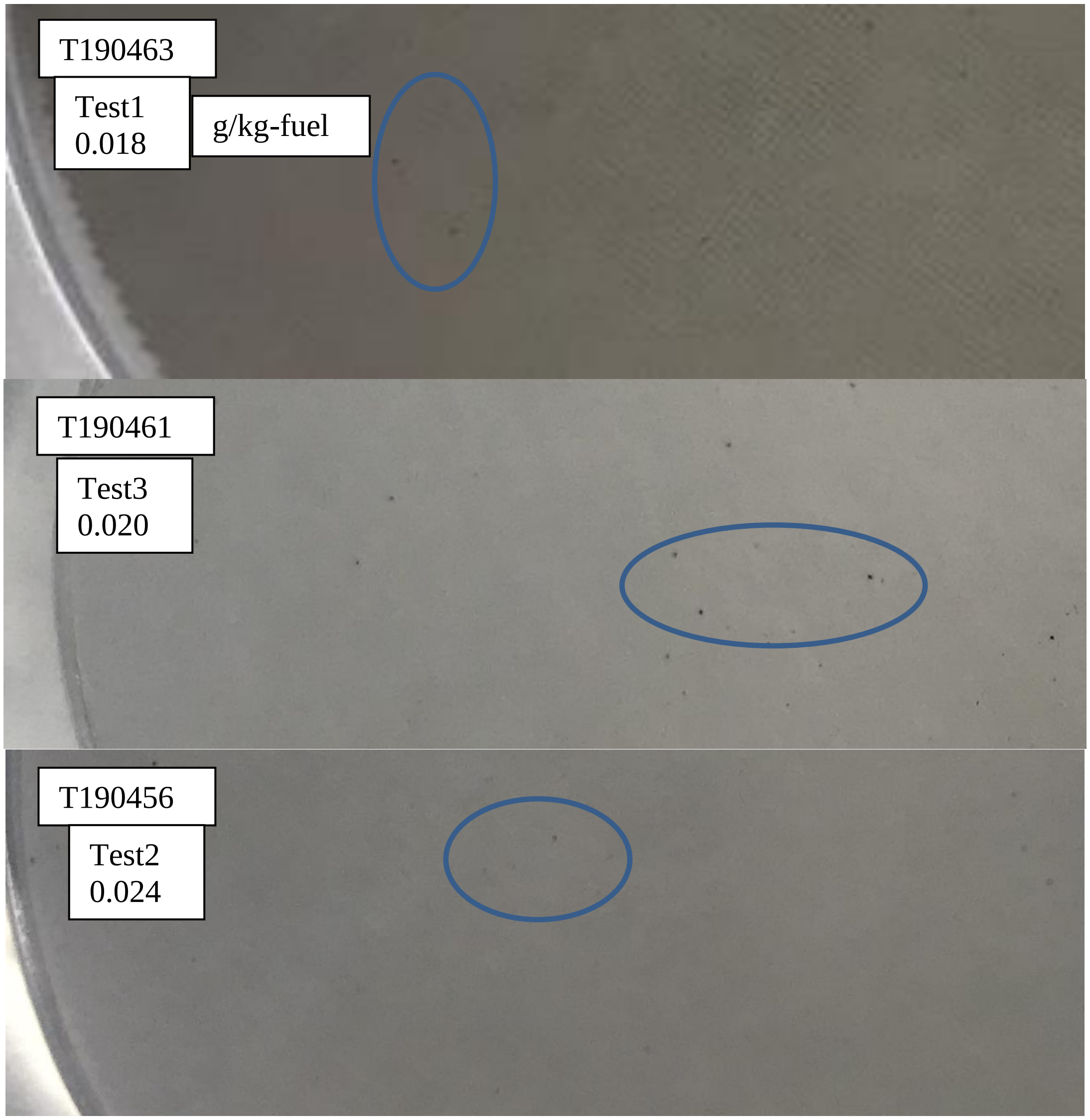

Figure 2-11 Filter spotting for tests 1, 2, and 3 (most observed spotting)

2.5.3 Toxics

SUMA canisters samplers were collected from the dilution tunnel between 11:01 and 12:24 and from the raw exhaust after 12:50, see Table 2-3. The dilute samples resulted in detectable quantities of C2-C4 analytes, but for the raw, undiluted samples, all the analyte responses below C5 were below the Sample Reporting Limit (SRL), see Table 2-4. The EPA 3C analysis showed 1.5% CO2 in the dilute measurement and 10.5% CO2 in the raw stack sample, suggesting the samplers were labeled and analyzed correctly. This suggests there may be a contamination in the dilution air utilized for the dilute BTEX samples.

The raw samples were used in the report analysis and this finding doesn't impact to overall discussion. Future BTEX samples will consider this impact on our sampling system especially when testing for lighter HC fuels.

Table 2-3 Summary of BETX sampling locations

BTEX				
Start Time	Dur	Flow	ID	Comment
hh:mm	min	slpm		
11:01	24	0.5	BTX6123	Dil tunnel
12:24	28	0.5	BTX6121	Dil tunnel
12:52	3	-	BTX6124	Raw stack grab
12:55	3	-	BTX6126	Raw stack grab

Table 2-4 Summary of BTEX concentrations C2-C4 dilute vs stack discussion

Analyte	MM		Diulte		Stack	
			#1	#2	#3	#4
Ethylene	28.1	C2H4	<SRL	<SRL	<SRL	<SRL
Acetylene	26.0	C2H2	1.88	<SRL	<SRL	<SRL
Ethane	30.1	C2H6	3.32	3.12	<SRL	<SRL
Propylene	42.1	C3H6	<SRL	<SRL	<SRL	<SRL
Propane	44.1	C3H8	16.1	9.16	<SRL	<SRL
Isobutane	58.1	C4H10	7.14	10.5	<SRL	<SRL
1-Butene	56.1	C4H8	<SRL	<SRL	<SRL	<SRL
1,3-Butadiene	54.1	C4H6	<SRL	<SRL	<SRL	<SRL
n-Butane	58.1	C4H10	2.24	3.44	<SRL	<SRL

3 Results

The emission results for the Alfa Laval auxiliary boiler installed on a tanker are described in this section. The results are based on the operation of the boiler under in-use conditions during fuel off-load in a Northern California port. The estimated load condition is 65%. There were some data corrections performed and these corrections are explained in Section 2.5. This section presents the results of the final data set, where all data points are available in Appendix F.

The result section is divided into three sub sections gaseous, PM (PM mass and composition and BC), and toxics. All error bars and standard deviations (stdev) presented are based on one sigma (σ) uncertainty.

3.1 Gaseous

The gaseous emissions include NO_x, CO, CO_2, and SO_2. The SO_2 emissions were both measured and calculated where the calculated values are used in this report. The gaseous emissions are shown in Table 3-1 (averages), Table 3-3 (stdev) and Figure 3-1. The boiler $fsCO_2$ emissions were 3026 g/kg-fuel. This is similar (with-in 2%) to previous testing of a modern auxiliary boiler on a container vessel. The close agreement suggests both boiler tests were performed under similar conditions.

The fuel specific (fs) NO_x emissions averaged 2.86 ± 0.18, CO 0.06 ± 0.064, and SO_2 0.94 g/kg-fuel. The $fsNO_x$ emissions were slightly higher, with-in 50%, to previous testing of a modern container vessel auxiliary boiler tested on low sulfur MGO and ULSFO fuels (0.038 S and 0.089 S respectively) (Johnson et al 2019), but over two times lower (2.2) than the emissions on a tanker vessel auxiliary boiler tested on high sulfur HFO fuel (2.85% S) (Agrawal et al 2008). The CO emissions were 6.9 times lower than the boiler operating on HFO fuel. The boiler SO_2 emissions were lower for the low sulfur fuel compared to a high sulfur HFO fuels, lower by a factor of 58 (Agrawal et al 2008). The main difference is a result of the sulfur weight fraction in the fuel.

Table 3-1 Summary of Emissions Measured by UCR (ave)

Boiler	Carb. FC	Units	Average Species					
Load	kg/hr		NOx	CO	CO2	calc. SO2	PM2.5	PM_eBC
65%	2460.4	g/hr	7051.0	154.7	7445560	2321.0	53.7	2.9
65%	2460.4	g/kg-fuel	2.86	0.064	3026.1	0.943	0.022	0.0012

Table 3-2 Summary of Emissions Measured by UCR (stdev)

Boiler	Carb. FC	Units	Stdev Species					
Load	kg/hr		NOx	CO	CO2	calc. SO2	PM2.5	PM_eBC
65%	2460.410	g/hr	0.261	0.063	0.434	0.000	0.004	0.0028
65%	2460.410	g/kg-fuel	0.175	0.055	0.162	0.050	0.004	0.0004

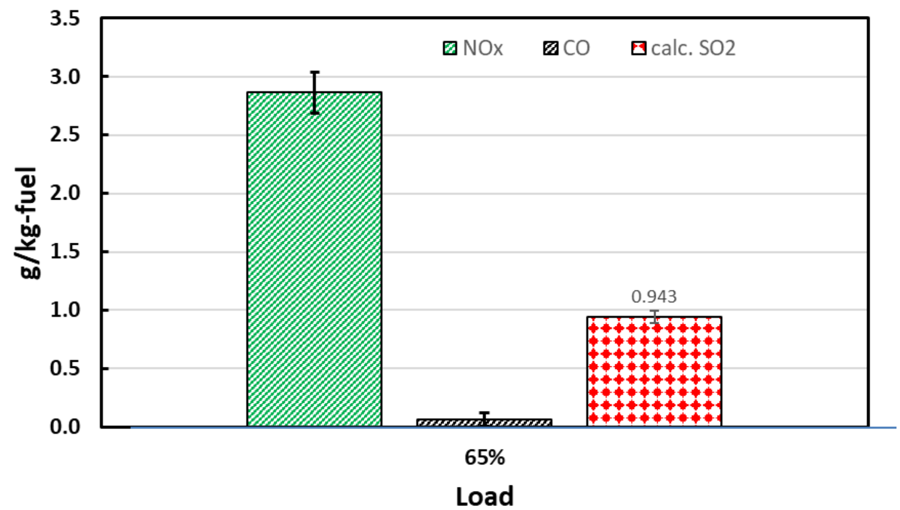

Figure 3-1 NOx, CO, and SO2 boiler emissions (g/kg-fuel)

[1] SO2 is calculated from sulfur in the fuel and fuel usage.

3.2 PM

The PM emissions are organized by PM mass, PM composition (EC, OC, Sulfate), and equivalent BC (eBC), see Section 2.3 for a description of the PM measurement method and definitions.

The $PM_{2.5}$ mass and eBC emissions for the boiler are show in Table 3-1 and Figure 3-2. The average $PM_{2.5}$ emissions were 0.022 ± 0.004 g/kg-fuel and the eBC emissions were 0.0012±0.0004 g/kg-fuel. The $PM_{2.5}$ emissions were slightly lower, with-in 50%, to previous testing of a modern auxiliary boiler tested on low sulfur MGO and ULSFO fuels (Johnson et al 2019), but over 100 times lower (131) than the PM emissions on a boiler tested on high sulfur HFO fuel, (Agrawal et al 2008).

The boiler eBC emissions were higher (70%) than the previous testing of a modern boiler (Johnson et al 2018), but the soot concentration in the stack was similar and near the detection limits of the measurement method. This suggests the difference between the eBC emissions from the two modern boilers may be a result of detection limits. eBC emissions were not measured with a micro soot sensor during the 2008 tanker testing, but NIOSH EC mass was measured. The boiler eBC emissions was 120 times lower than the EC emission reported for the tanker operating on high sulfur fuels (Agrawal et al 2008). Johnson has shown the EC measurement method at ratios of EC/OC < 5%, like in Agrawal's study, are less accurate (Johnson et al 2016), thus it is not clear the benefit of the eBC or EC measurement difference between the modern and older boilers.

The speciated PM (EC, OC, and Sulfate) emissions are shown in Table 3-3 and Figure 3-2. The PM_EC was 0.56 mg/kg-fuel and the OC_PM was 21 mg/kg-fuel. The fraction of EC compared to the sum of EC+OC is 2.2% suggesting the EC fraction is low for the boiler emissions and OC fractions are larger. The sulfate PM is still being analyzed, but can be estimated from the fuel sulfur level. This is estimated at 11 mg/kg-fuel for a fuel sulfur level of 0. 0483%. With the estimated sulfur the PM composition is calculated to be approximately 68.5% organic, 30% sulfate, and 1.5% elemental.

Table 3-3 Summary of PM composition measured by UCR (ave)

Boiler	Carb. FC	Units	Average Species					
Load	kg/hr		PM_EC	PM_OC	PM_S	PM_TC	PM_OCcor	PM_TCcor
65%	2460.4	g/hr	1.400	51.218	-	79.356	61.461	89.599
65%	2460.4	g/kg-fuel	0.00056	0.021	-	0.032	0.025	0.036

[1] PM_S is represented as hydrated sulfate ions (H20SO46.55H20), PM_TC is the sum of PM_EC+PM_OC+PM_S, PM_OCcor = 1.2*PM_OC to correct for the hydrogen bonding estimate, and PM_TCcor = PM_EC+PM_OCcor_PM_S and should represent the total PM mass and, thus, be comparable to $PM_{2.5}$

Table 3-4 Summary of of PM composition measured by UCR (stdev)

Boiler	Carb. FC	Units	Stdev Species					
Load	kg/hr		PM_EC	PM_OC	PM_S	PM_TC	PM_OCcor	PM_TCcor
65%	2460.4	g/hr	0.001	0.007	-	0.006	0.008	0.008
65%	2460.4	g/kg-fuel	0.00032	0.004	-	0.003	0.004	0.004

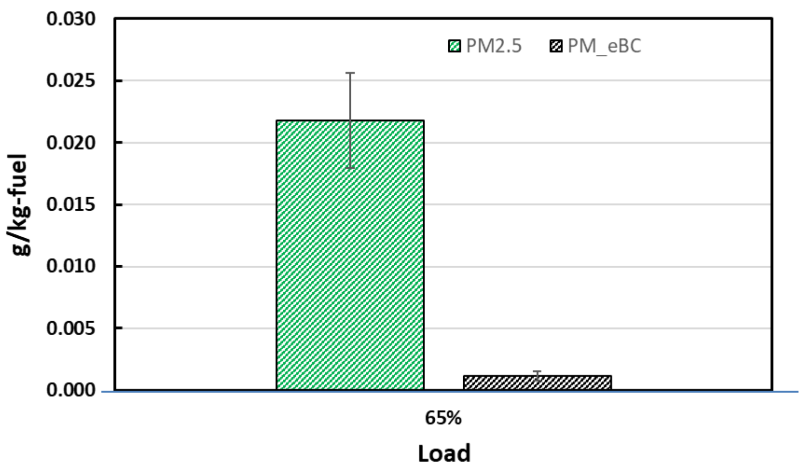

Figure 3-2 $PM_{2.5}$ and eBC emissions (g/kg fuel)

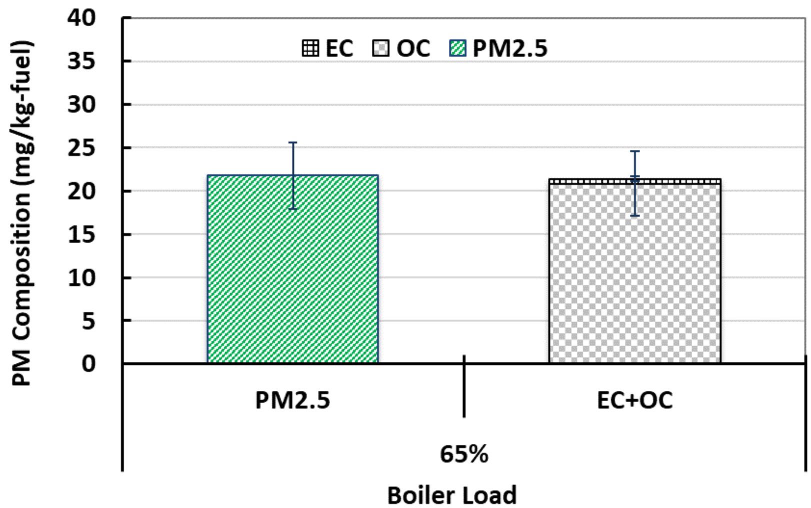

Figure 3-3 $PM_{2.5}$ and eBC emissions (mg/kg fuel)

3.3 Toxics

Toxics measurements were collected for the boiler tests. These include aldehydes and ketones, speciated hydrocarbons, and metals.

Aldehydes and ketones: The aldehydes and ketones are presented in Table 3-5. Only Formaldehyde, Acetaldehyde and Acrolein were analyzed, other species were not reported. The boiler emissions for Formaldehyde, Acetaldehyde and Acrolein were 0.401, 0.376, and 1.749 mg/kg-fuel. These results compare well with the modern boiler operating on MGO fuel from a container vessel. Both modern boilers operating on MGO fuel (container and tanker) emission results showed lower Formaldehyde emissions compared to the container boiler emissions when operating on low sulfur HFO fuel. Additionally, modern boilers operating on MGO fuels appear to have lower Acetaldehyde and Acetone emissions compared to the boiler tested by Agrawal (Agrawal et al 2008).

Table 3-5 Average Aldehydes and ketone emissions by fuel by test load.

Fuel	Load	Fuel Use kg/hr	Units	Formaldehyde			Acetaldehyde			Acrolein		
MGO	65%	2460	mg/hr	976.6	±	-	917.0	±	-	4263.1	±	-
MGO	65%	2460	mg/kg-fuel	0.401	±	-	0.376	±	-	1.749	±	-

[1] Statistical student t.test was not performed due to only one sample collected. Expected uncertainty from other replicate tests from boilers is ± 15%.

BTEX speciated hydrocarbons: The total PAMS, TNMHC, and selected species are presented in Table 3-6. The total PAMS were low and just above the Sample Report Limit (SRL) at 2 ppb and the total NMHC were 249 ppb on average. On a mass basis, the total PAMS and TNMHC were 0.0033 and 0.516 mg/kg-fuel, see Table 3-7. Other selected speciated HCs (C4-C8) are shown in Table 3-7 which were all below the SRL where the values reported represent an upper limit to their measurement this is why they are reported with the "<" sign. The speciated HCs (C4-C8) are higher during this modern boiler test compared to those reported by Agrawal (Agrawal et al 2008). One reason for the higher emissions in this testing may be due to different sample detection limits between the laboratories. The full report of speciated HCs (C2-C12) is provided in Appendix F. Also, during the previous study, PAHs were collected which were not collected in this study so that comparison is not available.

Table 3-6 EPA 3C, total PAMS, and TNMHC results, raw stack

Analyte	Stack EPA 3C		
	#1	#2	Ave
Dilution Factor	1.97	1.79	1.88
H_2	<2.0%	<1.8%	<1.8%
Ar/O_2	7.5%	7.5%	7.5%
N_2	82.0%	82.0%	82.0%
CO	<0.2%	<0.2%	<0.2%
CO_2	10.4%	10.5%	10.5%
CH_4	<0.2%	<0.2%	<0.2%
1,3 Butadiene (ppbC)	<SRL	<SRL	<SRL
Total PAMS (ppbC)	1.99	2.04	2.02
TNMHC (ppbC)	309	189	249

Table 3-7 Selected speciated hydrocarbons (C4-C8) mg/kg-hr

Analyte	Conc. ppb	mg/kg-fuel
1,3-Butadiene	<SRL	< 0.00907
Benzene	<SRL	< 0.00874
Toluene	<SRL	< 0.00883
m/p-Xylenes	<SRL	< 0.00891
Ethylbenzene	<SRL	< 0.00891
o-Xylene	<SRL	< 0.00891
Total PAMS	2.02	0.00332
TNMHC	249.0	0.516

[1] Total PAMS and TNMHC utilized propane for molar mass. For other species see Appendix F for the full list

Metals: The metal results for the boiler at 65% load are shown in Table 3-8 and Table 3-9. The full list of metal results can be found in Appendix F. These are in progress. AQMD agreed to perform this once the quarantine is lifted.

Table 3-8 Average selected metals with 1 σ error bars, 1 of 2

Fuel	Units	Mg			AL			Si			P			S		
MGO	mg/hr	-	±	-	-	±	-	-	±	-	-	±	-	-	±	-
MGO	mg/kg-fuel	-	±	-	-	±	-	-	±	-	-	±	-	-	±	-

Table 3-9 Average selected metals with 1 σ error bars, 2 of 2.

Fuel	Units	Cl			V			FE			NI		
MGO	mg/hr	-	±	-	-	±	-	-	±	-	-	±	-
MGO	mg/kg-fuel	-	±	-	-	±	-	-	±	-	-	±	-

4 Summary

Emissions measurements were made on from a modern auxiliary boiler on a tanker ship while it offloads fuel with-in a port in Northern California where the main engine was off. The auxiliary boiler was operated on MGO fuel and operated at an estimated 65% load. Emissions were measured following ISO and CFR methods for gaseous, and PM (total mass, elemental, and organic carbon species, sulfated PM). Boiler sampling also include toxics to help the CARB update its boiler emissions inventory. Dilution ratios and filter temperatures, as specified in 1065, were met during this testing.

A summary of the results for the testing is as follows:

- The emissions were slightly unstable at the start of testing, but were found to be stable for the segments analyzed. The reported data set is representative of valid measurements suggesting the results are representative of a properly operating boiler.
- The boiler fuel flow rate was meausred at 2460 kg/hr utilizing direct measurment of exhaust flow and carbon balance from emissions species. This agrees well with the reported fuel rate that ranged from 2268 to 2722 kg/hr according to the Chief. The corresponding exhaust flow at the 2460 kg/hr fuel rate was 35,639 m3/hr.
- The boiler fuel specific (fs) CO_2 emissions were 3026 g/kg-fuel. This is similar to previous testing of a modern auxiliary boiler on a container vessel.
- The boiler fsNO_x emissions averaged 2.86 ± 0.18, CO 0.06 ± 0.064, and SO_2 0.94 g/kg-fuel. The fsNO_x emissions were slightly higher, with-in 50%, to previous testing of a modern container vessel auxiliary boiler tested on low sulfur MGO and ULSFO fuels, but over two times lower (2.2) than the emissions on a tanker vessel auxiliary boiler tested on high sulfur HFO fuel. The CO emissions were 6.9 times lower than the boiler operating on HFO fuel.
- The boiler fsSO_2 emissions were lower for the low sulfur fuel compared to a high sulfur HFO fuels by a factor of 58
- fs$PM_{2.5}$ emissions were 0.022 ± 0.004 g/kg-fuel and were slightly lower to previous testing of a modern auxiliary boiler tested on low sulfur MGO and ULSFO fuels, but over 100 times lower (131) than the PM emissions on a boiler tested on high sulfur HFO fuel. The main difference between boiler PM emissions on low and high sulfur fuels is the sulfur content of the fuel.
- The fs_eBC emissions were 0.0012±0.0004 g/kg-fuel and were about the same for a previous modern boiler tested, but about 120 times lower than the fsEC emission reported for an older boiler tested on a tanker. The methods were not the same and there may be questions for this large difference.
- The fsPM composition (EC, OC, and Sulfate) were 0.56, 21, and 11 mg/kg-fuel respectively. The sulfute PM emissions were calculated and will be udpated with measured values once the state shut down has been lifted.
- The metals emissions were… Waiting on the analysis due to the state shut down.

- The boiler emissions for Formaldehyde, Acetaldehyde and Acrolein were 0.401, 0.376, and 1.749 mg/kg-fuel. These results compare well with the modern boiler operating on MGO fuel test from a container vessel. Modern boilers operating on MGO fuels appear to have lower Acetaldehyde and Acetone emissions compared to older boiler tested on HFO fuels.
- The total speciated HCs (C2-C12) PAMS and TNMHC were 0.0033 and 0.516 mg/kg-fuel. The PAMS measurements were at the detection limit of the measurement method and thus, could not be compared properly to the previous testing on an older boiler tested on a high sulfur HFO fuel.

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Appendix A – Sample Collection Methods

ISO 8178-1[4] and ISO 8178-2[5] specify the measurement and evaluation methods for gaseous and particulate exhaust emissions when combined with combinations of engine load and speed provided in ISO 8178- *4: Test cycles for different engine applications*. The emission results represent the mass rate of emissions per unit of work accomplished. Specific emission factors are based on brake power measured at the crankshaft, the engine being equipped only with the standard auxiliaries necessary for its operation. Per ISO, auxiliary losses are <5 % of the maximum observed power. IMO ship pollution rules and measurement methods are contained in the "International Convention on the Prevention of Pollution from Ships", known as MARPOL 73/78[6], and sets limits on NO_x and SO_x emissions from ship exhausts. The intent of this protocol was to conform as closely as practical to both the ISO and IMO standards.

Gaseous and Particulate Emissions

A properly designed sampling system is essential for accurate collection of a representative sample from the exhaust and subsequent analysis. ISO points out that particulate must be collected in either a full flow or partial flow dilution system and UCR chose the partial flow dilution system as shown in Figure A-1.

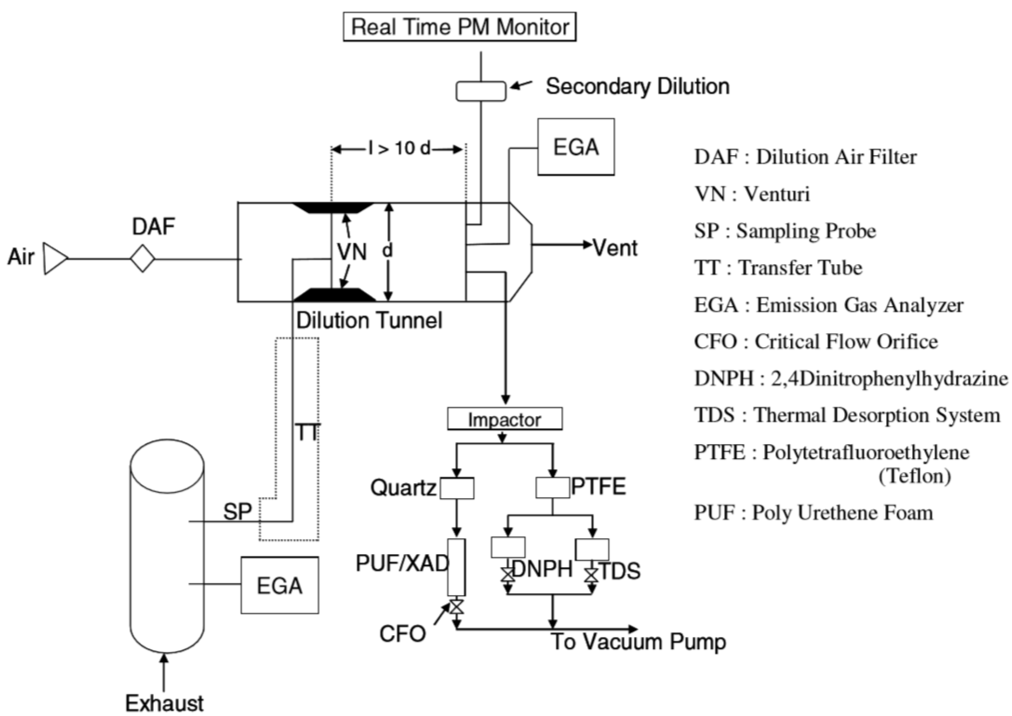


Figure A-1 Partial Flow Dilution System

[4] International Standards Organization, IS0 8178-1, *Reciprocating internal combustion engines - Exhaust emission measurement -Part 1: Test-bed measurement of gaseous particulate exhaust emissions,* First edition 1996-08-l5

[5] International Standards Organization, IS0 8178-2, *Reciprocating internal combustion engines - Exhaust emission measurement -Part 2: Measurement of gaseous and particulate exhaust emissions at site,* First edition 1996-08-l5

[6] International Maritime Organization, *Annex VI of MARPOL 73/78 "Regulations for the Prevention of Air Pollution from Ships and NOx Technical Code*".

The flow in the dilution system eliminates water condensation in the dilution tunnel and sampling systems and maintains the temperature of the diluted exhaust gas at <52°C before the filters. ISO cautions that the advantages of partial flow dilution systems can be lost to potential problems such as: losing particulates in the transfer tube, failing to take a representative sample from the engine exhaust and inaccurately determining the dilution ratio.

An overview of UCR's partial dilution system is shown in Figure A-1. Raw exhaust gas is transferred from the exhaust pipe (EP) through a sampling probe (SP) and the transfer tube (TT) to a dilution tunnel (DT) due to the negative pressure created by the venturi (VN) in DT. The gas flow rate through TT depends on the momentum exchange at the venturi zone and is therefore affected by the absolute temperature of the gas at the exit of TT. Consequently, the exhaust split for a given tunnel flow rate is not constant, and the dilution ratio at low load is slightly lower than at high load. More detail on the key components is provided in Table A-1.

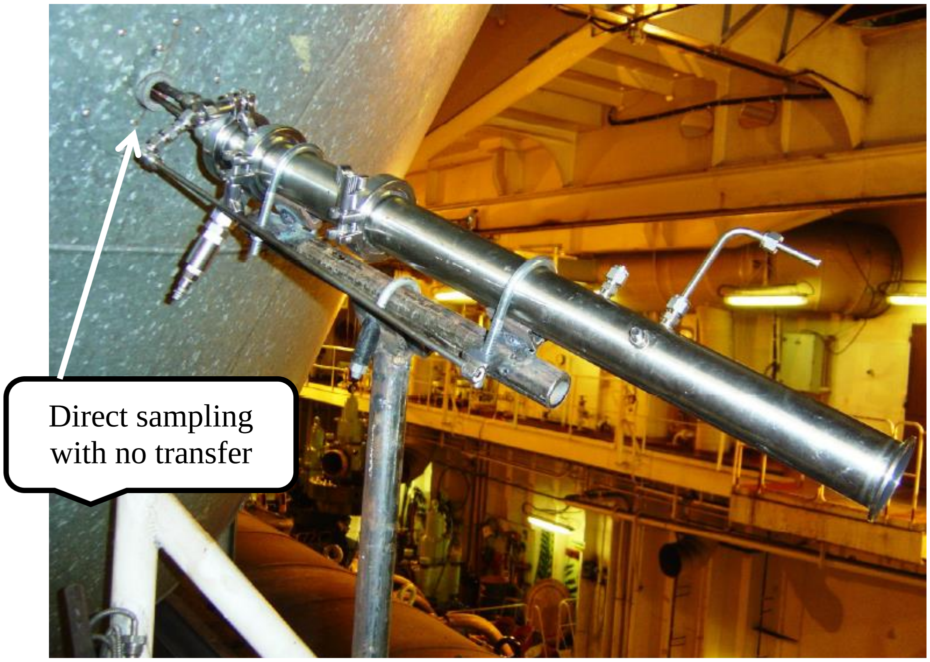


Figure A-2 measurement layout on an engine exhaust stack

Dilution Air System

40 CFR Part 1065 recommends dilution air to be 20 to 30°C and ISO recommends 25 ±5°C. Both also recommend using filtered and charcoal scrubbed air to eliminate background hydrocarbons. The dilution air may be dehumidified. The system can be described as follows: The pressure is reduced to around 40 psig, a liquid knock-out vessel, desiccant to remove moisture with silica gel containing an indicator, hydrocarbon removal with activated charcoal, and a HEPA filter for the fine aerosols that might be present in the supply air. The silica gel and activated carbon are changed for each field campaign. Figure A-3 shows the field processing unit in its transport case. In the field the case is used as a framework for supporting the unit.

Table A-1 Components of a Sampling System: ISO Criteria & UCR Design

Section	Selected ISO and IMO Criteria	UCR Design
Exhaust Pipe (EP)	In the sampling section, the gas velocity is > 10 m/s, except at idle, and bends are minimized to reduce inertial deposition of PM. Sample collection of 10 pipe diameters of straight pipe upstream is recommended and performed where possible. For some tight configurations use good engineering judgment.	UCR follows the ISO recommendation, when practical.
Sampling Probe (SP) -	The minimum inside diameter is 4 mm and the probe is an open tube facing upstream on the exhaust pipe centerline. No IMO code.	UCR uses a stainless steel tube with diameter of 8mm placed near the center line.
Transfer Tube (TT)	• As short as possible and < 5 m in length; • Equal to/greater than probe diameter & < 25 mm diameter; • TTs insulated. For TTs > 1m, heat wall temperature to a minimum of 250°C or set for < 5% thermophoretic losses of PM.	UCR uses a transfer tube of 0.15 m (6 inches). Additionally the sample tube insertion length varies with stack diameter, but typically penetrates at least 10%, but not more than 50% of the stack diameter.
Dilution Tunnel (DT)	• shall be of a sufficient length to cause complete mixing of the exhaust and dilution air under turbulent flow conditions; • shall be at least 75 mm inside diameter (ID) for the fractional sampling type, constructed of stainless steel with a thickness of > 1.5 mm.	UCR uses fractional sampling; stainless steel tunnel has an ID of 50mm and thickness of 1.5mm.
Venturi (VN) --	The pressure drop across the venturi in the DT creates suction at the exit of the transfer tube TT and the gas flow rate through TT is basically proportional to the flow rate of the dilution air and pressure drop.	Venturi proprietary design provided by MAN B&W; provides turbulent mixing.
Exhaust Gas Analyzers (EGA)	One or several analyzers may be used to determine the concentrations. Calibration and accuracy for the analyzers are like those for measuring the gaseous emissions.	UCR uses a 5-gas analyzer meeting IMO/ISO specs

Figure A-3 Field Processing Unit for Purifying Dilution Air in Carrying Case

Calculating the Dilution Ratio

According to ISO 8178, “it is essential that the dilution ratio be determined very accurately” for a partial flow dilution system such as what UCR uses. The dilution ratio is simply calculated from measured gas concentrations of CO_2 and/or NO_x in the raw exhaust gas, the diluted exhaust gas and the dilution air. UCR has found it useful to independently determine the dilution ratio from both CO_2 and NO_x and compare the values to ensure that they are within ±10%. UCR’s experience indicates the independently determined dilution ratios are usually within 5%. At systematic deviations within this range, the measured dilution ratio can be corrected, using the calculated dilution ratio. According to ISO, dilution air is set to obtain a maximum filter face temperature of <52°C and the dilution ratio shall be > 4.

Dilution System Integrity Check

ISO describes the necessity of measuring all flows accurately with traceable methods and provides a path and metric to quantifying the leakage in the analyzer circuits. UCR has adopted the leakage test and its metrics as a check for the dilution system. According to ISO the maximum allowable leakage rate on the vacuum side shall be 0.5 % of the in-use flow rate for the portion of the system being checked. Such a low leakage rate allows confidence in the integrity of the partial flow system and its dilution tunnel. Experience has taught UCR that the flow rate selected should be the lowest rate in the system under test.

Measuring the Gaseous Emissions: CO, CO_2, NO_x, O_2, SO_2

Measurement of the concentration of the main gaseous constituents is one of the key activities in measuring emission factors. This section covers the ISO/IMO protocols used by UCR. For SO_2, ISO/CFR recommends that the concentration of SO_2 is calculated based on the fact that 97.75% of the fuel sulfur is converted to SO_2 (40 CFR Part 1065). UCR agrees with this recommendation and the enclosed SO2 reported emissions are calculated from fuel sulfur levels.

Measuring Gaseous Emissions: ISO & IMO Criteria

ISO specifies that either one or two sampling probes located in close proximity in the raw gas can be used and the sample split for different analyzers. However, in no case can condensation of exhaust components, including water and sulfuric acid, occur at any point of the analytical system. ISO specifies the analytical instruments for determining the gaseous concentration in either raw or diluted exhaust gases.

- Non-dispersive infrared analyzer (NDIR) for the measurement of carbon monoxide and carbon dioxide;
- Heated chemiluminescent detector (HCLD) or equivalent for measurement of nitrogen oxides;
- Paramagnetic detector (PMD) or equivalent for measurement of oxygen.

ISO states the range of the analyzers shall accurately cover the anticipated concentration of the gases and recorded values between 15% and 100% of full scale. A calibration curve with five points is specified. However, with modern electronic recording devices, like a computer, ISO allows the range to be expanded with additional calibrations. ISO details instructions for establishing a calibration curve below 15%. In general, calibration curves must be $< \pm 2$ % of each calibration point and be $< \pm 1$ % of full scale zero.

ISO outlines their verification method. Each operating range is checked prior to analysis by using a zero gas and a span gas whose nominal value is more than 80 % of full scale of the measuring range. If, for the two points considered, the value found does not differ by more than ±4 % of full scale from the declared reference value, the adjustment parameters may be modified. If >4%, a new calibration curve is needed.

ISO, IMO, and CFR specify the operation of the HCLD. The efficiency of the converter used for the conversion of NO_2 into NO is tested prior to each calibration of the NO_x analyzer. 40 CFR Part 1065 requires 95% and recommends 98%. The efficiency of the converter shall be >95 % and will be evaluated prior to testing.

ISO requires measurement of the effects of exhaust gases on the measured values of CO, CO_2, NO_x, and O_2. Interference can either be positive or negative. Positive interference occurs in NDIR and PMD instruments where the interfering gas gives rise to the same effect as the gas being measured, but to a lesser degree. Negative interference occurs in NDIR instruments due to the interfering gas broadening the absorption band of the measured gas, and in HCLD instruments due to the interfering gas quenching the radiation. Interference checks are recommended prior to an analyzer's initial use and after major service intervals.

Measuring Gaseous Emissions: UCR Design

The concentrations of CO, CO_2, NO_x and O_2 in the raw exhaust and in the dilution tunnel are measured with a Horiba PG-250 portable multi-gas analyzer. The PG-250 simultaneously measures five separate gas components with methods recommended by the ISO/IMO and USEPA. The signal output of the instrument is connected to a laptop computer through an RS-232C interface to continuously record measured values. Major features include a built-in sample conditioning system with sample pump, filters, and a thermoelectric cooler. The performance of the PG-250 was tested and verified under the U.S. EPA ETV program.

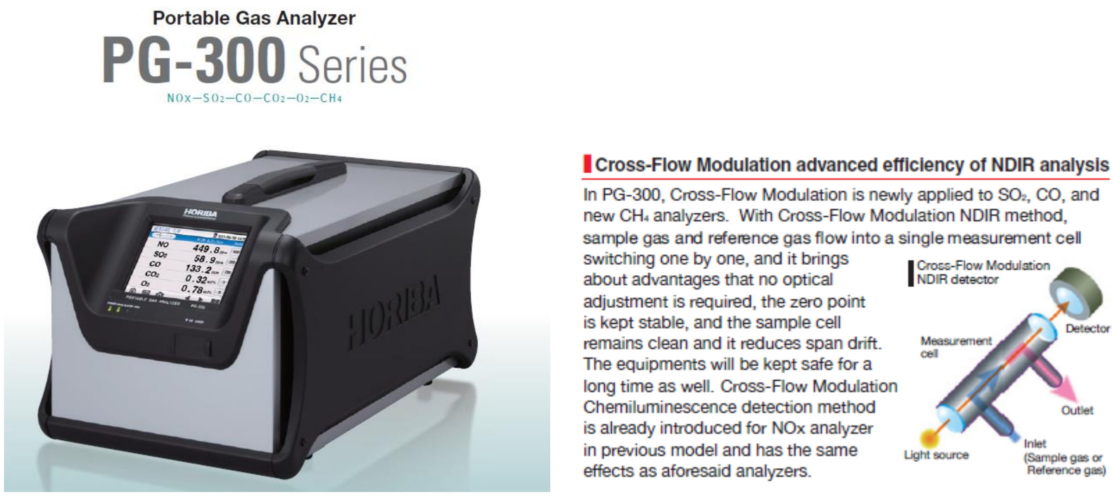


Figure A-4 Gas analyzer setup with measurement cell description

Details of the gases and the ranges for the Horiba instrument are shown in Table A-2. Note that the Horiba instrument measures sulfur oxides (SO_2); however, UCR follows the protocol in ISO which recommends calculation of the SO_2 level from the sulfur content of the fuel as the direct measurement for SO_2 is less precise than calculation. When an exhaust gas scrubber is present, UCR recommends measuring the SO_2 concentration after the scrubber since the fuel calculation approach will not be accurate due to scrubber SO_2 removal performance expectations.

Table A-2 Detector Method and Concentration Ranges for Monitor

Component	Detector	Ranges
Nitrogen Oxides (NOx)	Heated Chemiluminescence Detector (HCLD)	0-25, 50, 100, 250, 500, 1000, & 2500 ppmv
Carbon Monoxide (CO)	Non dispersive Infrared Absorption (NDIR). Cross flow modulation	0-200, 500, 1000, 2000, & 5000 ppmv
Carbon Dioxide (CO_2)	Non dispersive Infrared Absorption (NDIR)	0-5, 10, & 20 vol%
Sulfur Dioxide (SO_2)	Non dispersive Infrared Absorption (NDIR). Cross flow modulation	0-200, 500, 1000, & 3000 ppmv
Oxygen	Zirconium oxide sensor	0-5, 10, & 25 vol%

For quality control, UCR carries out analyzer checks with calibration gases both before and after each test to check for drift. Because the instrument measures the concentration of five gases, the calibration gases are a blend of several gases (super-blend) made to within 1% specifications. Experience has shown that the drift is within manufacturer specifications of ±1% full scale per day shown in Table A-3. The PG-250 meets the analyzer specifications in ISO 8178-1 Section 7.4 for repeatability, accuracy, noise, span drift, zero drift and gas drying.

Table A-3 Quality Specifications for the Horiba PG-250

Repeatability	±0.5% F.S. (NO_x: </= 100ppm range CO: </= 1,000ppm range) ±1.0% F. S.
Linearity	±2.0% F.S.
Drift	±1.0% F. S./day (${SO_2}$: ±2.0% F.S./day)

Replacement parts

Replacement part intervals assume 8 hours of operation per day.
Replacement interval may be more frequent depending on measurement gas conditions and use conditions.

[Consumable Items]

Name	Replace Every (general guideline)	Notes
Mist catcher	3 months	MC-025
Scrubber	3 months	For reference line
Air filter element	2 weeks	For reference line

[Replacement Parts]

Name	Replace Every (general guideline)	Notes
Pump	1 year	Replace when broken
NOx converter catalyst	1 year	For NOx analyzer*
Zero gas purifier unit catalyst	1 year	*
Ozone generator	1 year	For NOx analyzer*
Deozonizer	1 year	For NOx analyzer*
CR2032 battery	5 years	For clock backup
Galvanic O_2 cell	1 year	Replace when broken*

* Differs depending on model

Figure A-4b Gas analyzer replacement parts and maintenance

Measuring the Particulate Matter (PM) Emissions

ISO 8178-1 defines particulates as any material collected on a specified filter medium after diluting exhaust gases with clean, filtered air at a temperature of ≤ 52ºC (40 CFR Part 1065 is 47±5 °C), as measured at a point immediately upstream of the PM filter. The particulate consists of primarily carbon, condensed hydrocarbons, sulfates, associated water, and ash. Measuring particulates requires a dilution system and UCR selected a partial flow dilution system. The dilution system design completely eliminates water condensation in the dilution/sampling systems and maintains the temperature of the diluted exhaust gas at < 52°C immediately upstream of the filter holders (and is typically below 47°C also). IMO does not offer a protocol for measuring PM and thus a combination of ISO and CFR practices are adopted. A comparison of the ISO and UCR practices for sampling PM is shown in Table A-4.

Table A-4 Measuring Particulate by ISO and UCR Methods

	ISO	UCR
Dilution tunnel	Either full or partial flow	Partial flow
Tunnel & sampling system	Electrically conductive	Same
Pretreatment	None	Cyclone, removes >2.5µm
Filter material	PTFE coated glass fiber	Teflon (TFE)
Filter size, mm	47 (37mm stain diameter)	Same
Number of filters in series	Two	One
Number of filters in parallel	Only single filter	Two; 1 TFE & 1 Quartz
Number of filters per mode	Single or multiple	Single is typical unless looking at artifacts
Filter face temp. °C	≤ 52	Same
Filter face velocity, cm/sec	35 to 80.	~33
Pressure drop, kPa	For test <25	Same
Filter loading, µg	>500	500-1,000 + water w/sulfate, post PM control ~ 100
Weighing chamber	22±3°C & RH= 45%± 8	22±1 °C & dewpoint of 9.5 °C±1°C (typically < ±0.6°C)
Analytical balance, LDL µg	10	LDL = 3 and resolution 0.1
Flow measurement	Traceable method	Same
Flow calibration, months	< 3months	Every campaign

Sulfur content. According to ISO, particulates measured using IS0 8178 are "conclusively proven" to be effective for fuel sulfur levels up to 0.8%. UCR is often faced with measuring PM for fuels with sulfur content exceeding 0.8% and has adopted the 40 CFR Part 1065 sampling methodologies as no other method is prescribed for fuels with a higher sulfur content.

Calculating Exhaust Flow Rates

The calculated emission factor requires the measurement of the engine's exhaust flow rate. The exhaust gas flow can be determined by the following methods:

1. Direct Measurement Method
2. Carbon Balance Method
3. Air and Fuel Measurement Method
4. Air Pump method

Method 1: Direct Measurement of exhaust
Actual exhaust mass flow rate can be determined from the exhaust velocity, cross sectional area of the stack, and moisture and pressure measurements. The direct measurement method is a difficult technique, and precautions must be taken to minimize measurement errors. Details of the direct measurement method are provided in ISO 5167-1.

Method 2(a)-Carbon Balance
Carbon Balance is used to calculate the exhaust mass flow based on the measurement of fuel consumption and the exhaust gas concentrations with regard to the fuel characteristics. The method given is only valid for fuels without oxygen and nitrogen content, based on procedures used for EPA and ECE calculations. Detailed calculation steps of the Carbon Balance method are provided in annex A of ISO 8178-1. Basically: In…lbs fuel/time * wt% carbon * 44/12 → input of grams CO2 per time Out… vol % CO2 * (grams exhaust/time * 1/density exhaust) → exhaust CO2 per time
Note that the density = (mole wt*P)/(R* Temp) where P, T are at the analyzer conditions. For highly diluted exhaust, M ~ of the atmosphere.

Method 2(b)-Universal Carbon/Oxygen balance
The Universal Carbon/Oxygen Balance is used for the calculation of the exhaust mass flow. This method can be used when the fuel consumption is measurable and the fuel composition and the concentration of the exhaust components are known. It is applicable for fuels containing H, C, S, 0, N in known proportions. Detailed calculation steps of Carbon/Oxygen Balance method is provided in annex A of ISO 8178-1.

Method 3-Air and Fuel Measurement Method
This involves measurement of the air flow and the fuel flow. The calculation of the exhaust gas flow is provided in Section 7.2 of ISO 8178-1.

Method 4-Air Pump Method
Exhaust flow rate is calculated by assuming the engine is an air pump, meaning that the exhaust flow is equal to the intake air flow. The flow rate is determined from the overall engine displacement, and rpm; corrected for temperature and pressure of the inlet air and pumping efficiency. In the case of turbocharged engines, this is the boost pressure and intake manifold temperature. This method should not be used for diesel engines equipped with additional air input for cylinder exhaust discharge, called purge or scavenger air, unless the additional flow rate is known or can be determined.

Added Comments about UCR's Measurement of PM
In the field UCR uses a raw particulate sampling probe fitted close to and upstream of the raw gaseous sample probe and directs the PM sample to the dilution tunnel. There are two gas streams leaving the dilution tunnel; the major flow vented outside the tunnel and the minor flow directed

to a cyclone separator, sized to remove particles >2.5um. The line leaving the cyclone separator is split into two lines; each line has a 47 mm Gelman filter holder. One holder collects PM on a Teflon filter and the other collects PM on a quartz filter. UCR simultaneously collects PM on Teflon and quartz filters at each operating mode and analyzes the quartz filters utilizing the NIOSH or IMPROVE methods. UCR recommends the IMPROVE method over the NIOSH.

Briefly, total PM is collected on Pall Gelman (Ann Arbor, MI) 47 mm Teflon filters and weighed using a Mettler Toledo UMX2 microbalance with a 0.1 ug resolution. Before and after collection, the filters are conditioned for 24 hours in an environmentally controlled room (22±1 °C and dewpoint of 9.5 °C) and weighed daily until two consecutive weight measurements are within 3 µg or 2%. It is important to note that the simultaneous collection of PM on quartz and Teflo^{TM} filters provides a comparative check of PM mass measured by two independent methods for measuring PM mass.

Sulfur in the fuel produces SO_2 in the combustion process and some of the SO_2 becomes SO_3 in the exhaust and subsequently produces $H_2SO4 \bullet 6H_2O$ which is collected on the Teflon filter paper. After the final weights for the particulate laden Teflon filters have been determined a portion of the filter is punched out, extracted with High Performance Liquid Chromatography grade water and isopropyl alcohol and analyzed for sulfate ions by ion chromatography.

Measuring Real-Time Particulate Matter (PM) Emissions-DustTrak 8520

In addition to the filter-based PM mass measurements, UCR uses a Nephelometer (TSI DustTrak 8520) for continuous measurements of steady-state and transient data. The DustTrak is a portable, battery-operated laser photometer that gives real-time digital readout and has a built-in data logger. It measures light scattered (90 degree light scattering at 780nm near-infrared) by aerosol introduced into a sample chamber and displays the measured mass density in units of mg/m^3. As scattering per unit mass is a strong function of particle size and refractive index of the particle size distributions and as refractive indices in diesel exhaust strongly depend on the particular engine and operating condition, some question the accuracy of PM mass measurements. However, UCR always references the DustTrak results to filter based measurements and this approach has shown that mass scattering efficiencies for both on-road diesel exhaust and ambient fine particles have values around 3m^2/g.

Figure A-5 Picture of TSI DustTrak

Measuring Non-Regulated Gaseous Emissions

Neither ISO nor IMO provide a protocol for sampling and analyzing non-regulated emissions. UCR uses peer reviewed methods adapted to their PM dilution tunnel. The methods rely on added media to selectively collect hydrocarbons and PM fractions during the sampling process for subsequent off-line analysis. A secondary dilution is constructed to capture real time PM this same tunnel was used for DNPH and Canister samples. In addition, UCR collected raw grab samples of the

Appendix B – Quality Control

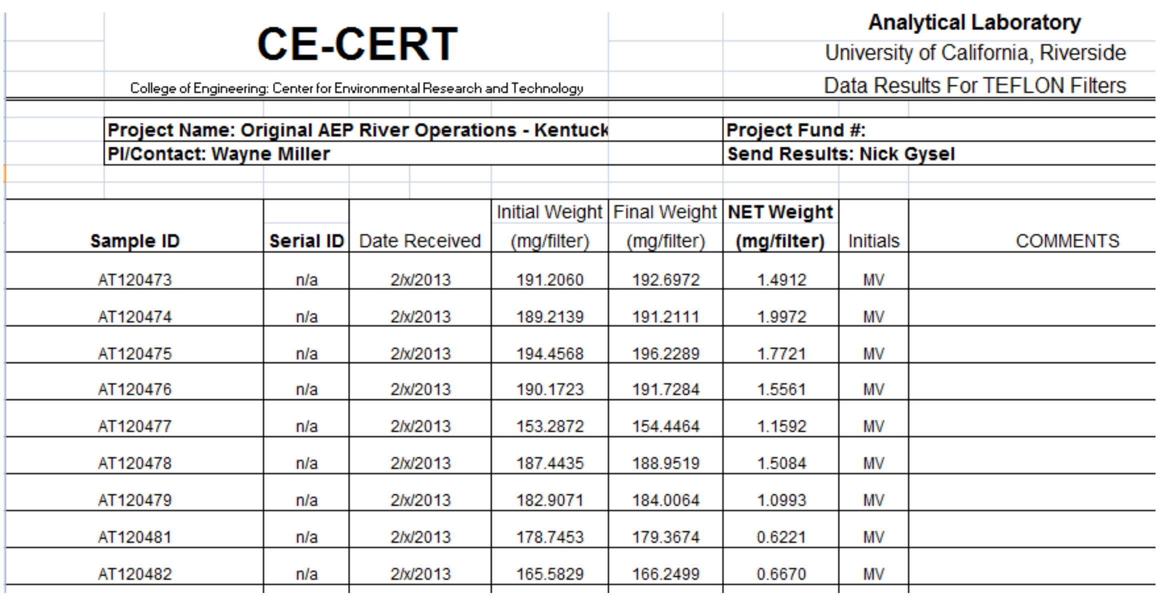
Pre-test calibrations
Prior to departing from UCR all systems will be verified and cleaned for the testing campaign. This included all instruments used during this testing project. Sample filters are checked and replaced if necessary.

On-site calibrations
Pre- and post-test calibrations were performed on the gaseous analyzer using NIST traceable calibration bottles. Dilution ratio was monitored and verified at least twice each test day. Leak checks were performed for the total $PM_{2.5}$ system prior testing for each setup.

Post-test and data validation
Post-test evaluation includes verifying consistent dilution ratios between points and data is compared to other test conditions that are similar.

The figure below (Figure B-1) is an example of a chain of custody form. This is the form used to track filter weights from the test to the laboratory. One form for the filter weights, BTEX, and EC/OC. This is just an example of media tracking that is used.

Figure B-2 is an example of UCR certified calibration bottles used for testing. Prior to using a new bottle the old one is verified with the new one as bottles can incorrect in their stated value. It is rare, but can happen.



CE-CERT

College of Engineering: Center for Environmental Research and Technology

Analytical Laboratory
University of California, Riverside
Data Results For TEFLON Filters

Project Name: Original AEP River Operations - Kentuck | **Project Fund #:**
PI/Contact: Wayne Miller | **Send Results: Nick Gysel**

Sample ID	Serial ID	Date Received	Initial Weight (mg/filter)	Final Weight (mg/filter)	NET Weight (mg/filter)	Initials	COMMENTS
AT120473	n/a	2/x/2013	191.2060	192.6972	1.4912	MV	
AT120474	n/a	2/x/2013	189.2139	191.2111	1.9972	MV	
AT120475	n/a	2/x/2013	194.4568	196.2289	1.7721	MV	
AT120476	n/a	2/x/2013	190.1723	191.7284	1.5561	MV	
AT120477	n/a	2/x/2013	153.2872	154.4464	1.1592	MV	
AT120478	n/a	2/x/2013	187.4435	188.9519	1.5084	MV	
AT120479	n/a	2/x/2013	182.9071	184.0064	1.0993	MV	
AT120481	n/a	2/x/2013	178.7453	179.3674	0.6221	MV	
AT120482	n/a	2/x/2013	165.5829	166.2499	0.6670	MV	

Figure B-1 Sample chain of custody form example

CERTIFICATE OF ANALYSIS

Primary Standard

Component	Requested Concentration	Certified Concentration	Analytical Principle	Analytical Accuracy
Carbon dioxide	**12 %**	**11.76 %**	**L**	**± 1%**
Carbon monoxide	**500 ppm**	**501 ppm**	**L**	**± 1%**
Nitric oxide	**2000 ppm**	**1929 ppm**	**U**	**± 1%**
Propane	**500 ppm**	**515 ppm**	**Q**	**± 1%**
Nitrogen	**balance**	**balance**		

Analytical Instruments: **Horiba Instruments Inc.~VIA-510~NDIR~Non-dispersive Infrared**
Thermo Environmental~42i~Nitric Oxide Analyzer~Chemiluminescence
Horiba Instruments Inc.~FIA-510~THC- Total Hydrocarbon Analyzer~FID - Flame Ionization Detector

Cylinder Style: **AS**
Cylinder Pressure @70F: **2000 psig**
Cylinder Volume: **140 ft3**
Valve Outlet Connection: **CGA-660**
Cylinder No(s). **CC92665**
Comments: **[NOx] = 1947 ppm for reference only.**
All values not valid below 150 psig.

Filling Method: **Gravimetric**
Date of Fill: **10/31/2012**
Expiration Date: **11/06/2014**

Chas Manning (RMC)
Analyst: **Chas Manning**

Nelson Ma
Approved Signer: **Nelson Ma**

Figure B-2 One percent sample protocol gas analysis example

Appendix C –Test Assumptions

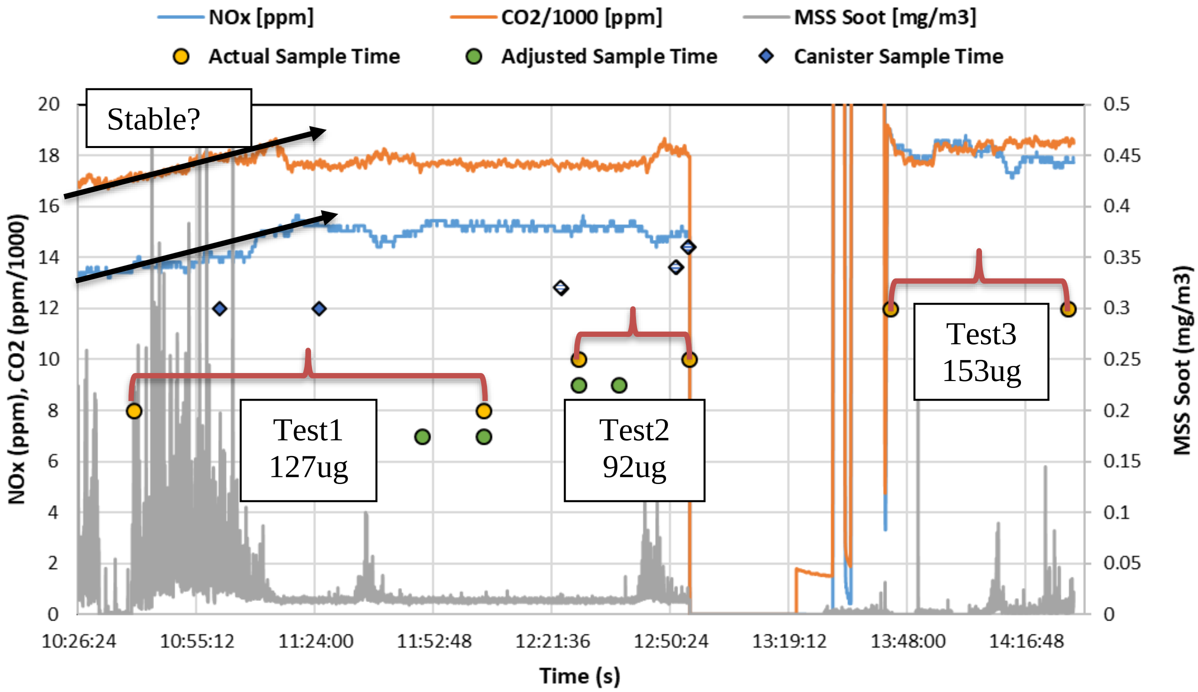


Figure C-1: Real Time Response for selected emissions species with test notes

Initial sample times were chosen based on previous projects and soot levels. Initial sampling was started as soon as possible with a total sample time of 75 minutes. During the second test, a power failure on the ship cut testing short for a total sample time of 27 minutes. The final test sample was started as soon as power was restored and lasted as long as possible for a total testing time of 43 minutes. The real time data shows that all sample times experienced unstable data trends. The first test experienced unstable CO2, NOx, and Soot data at the beginning of the test most likely due to the boiler not being fully warmed up. The second test experienced soot, NOx, and CO2 spikes toward the end of the test. The third test showed elevated levels of CO2 and NOx for unknown reasons.

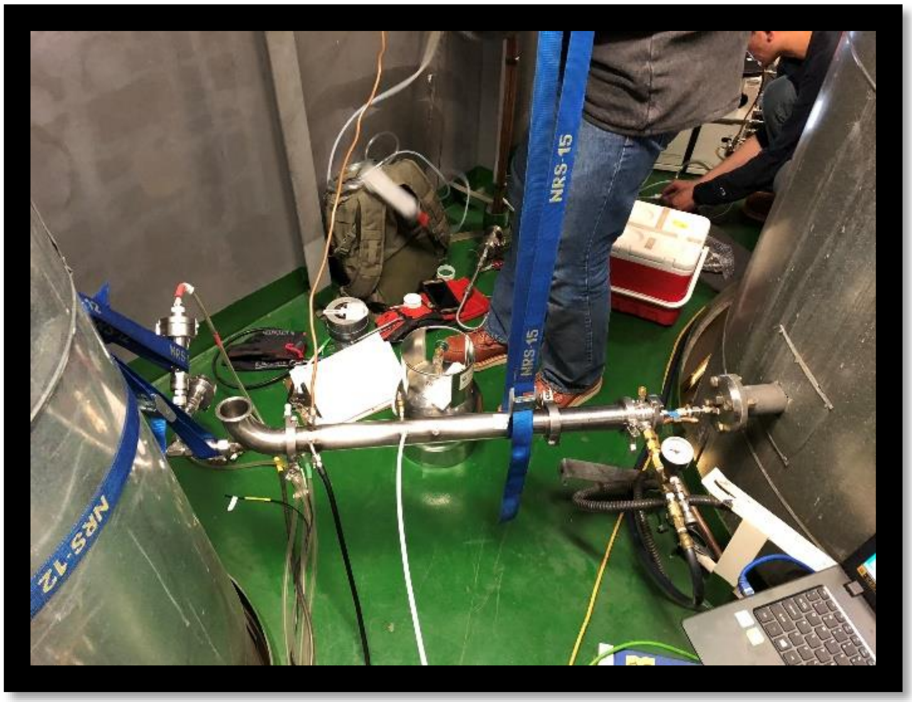


Figure C-2 Installation showing removal of cyclone.

Due to the unstable nature of all 3 test points, modified sampling times were used to capture stable data during the course of testing. PM results were averaged with the soot data from the original tests, and a weighting factor was used to calculate PM mass of the modified sample times.

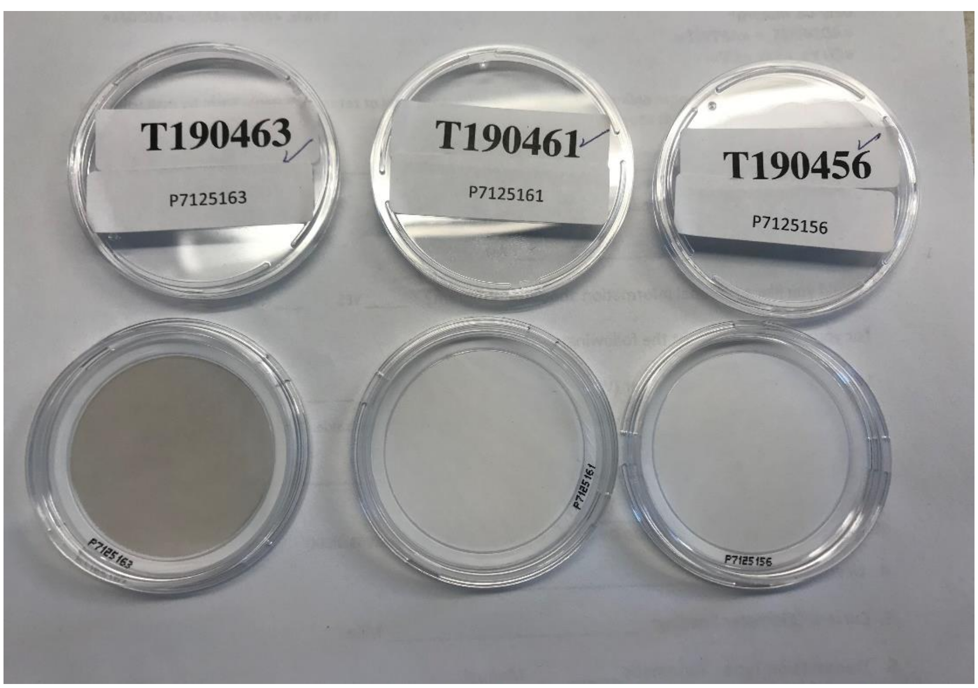


Figure C-3 Sample filters Test 1, 2, and 3
[1] The filter weights were 127, 153, and 92 ug from left to right.

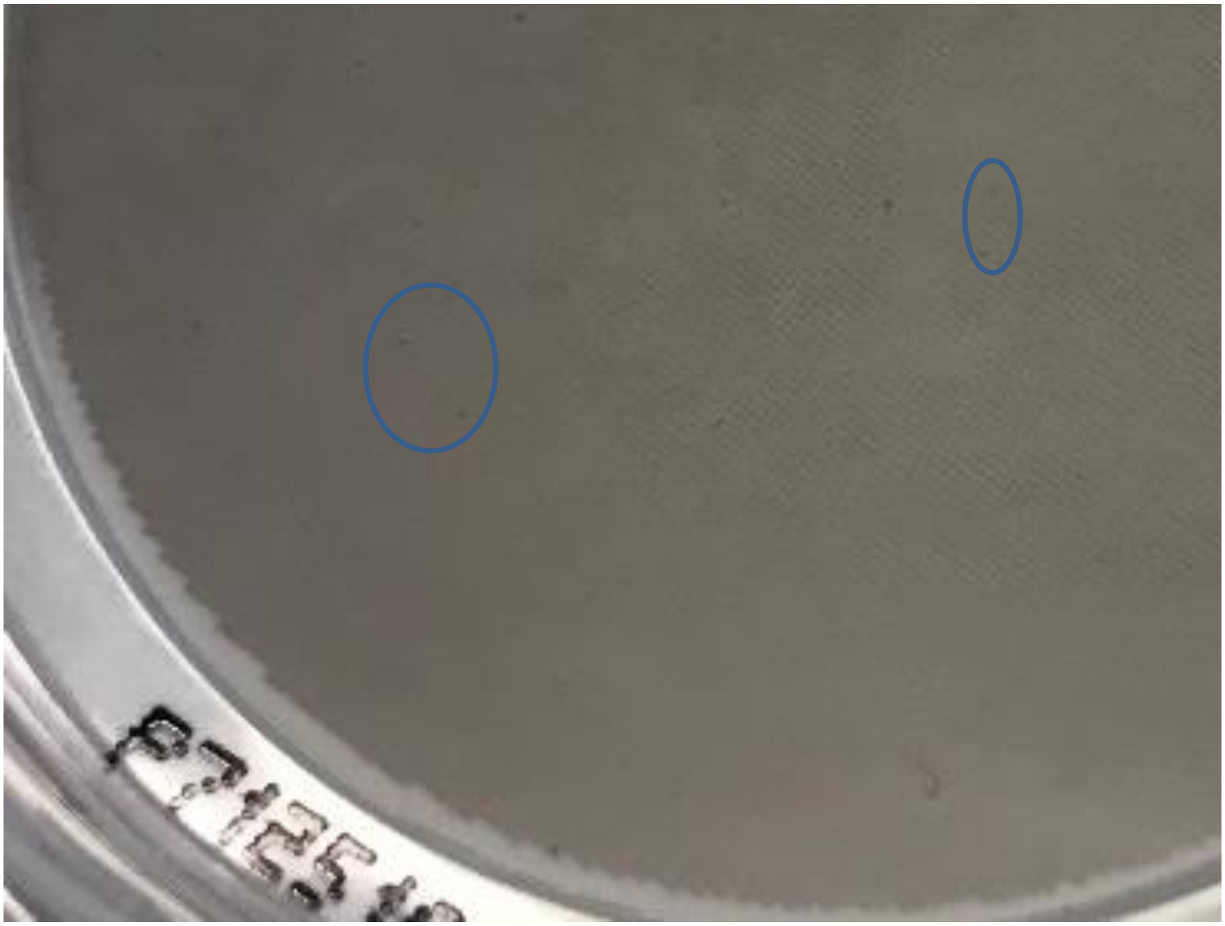


Figure C-4 Sample filter T190463 (medium spotting)

Figure C-5 Sample filter T190461 (heavy-ish spotting)

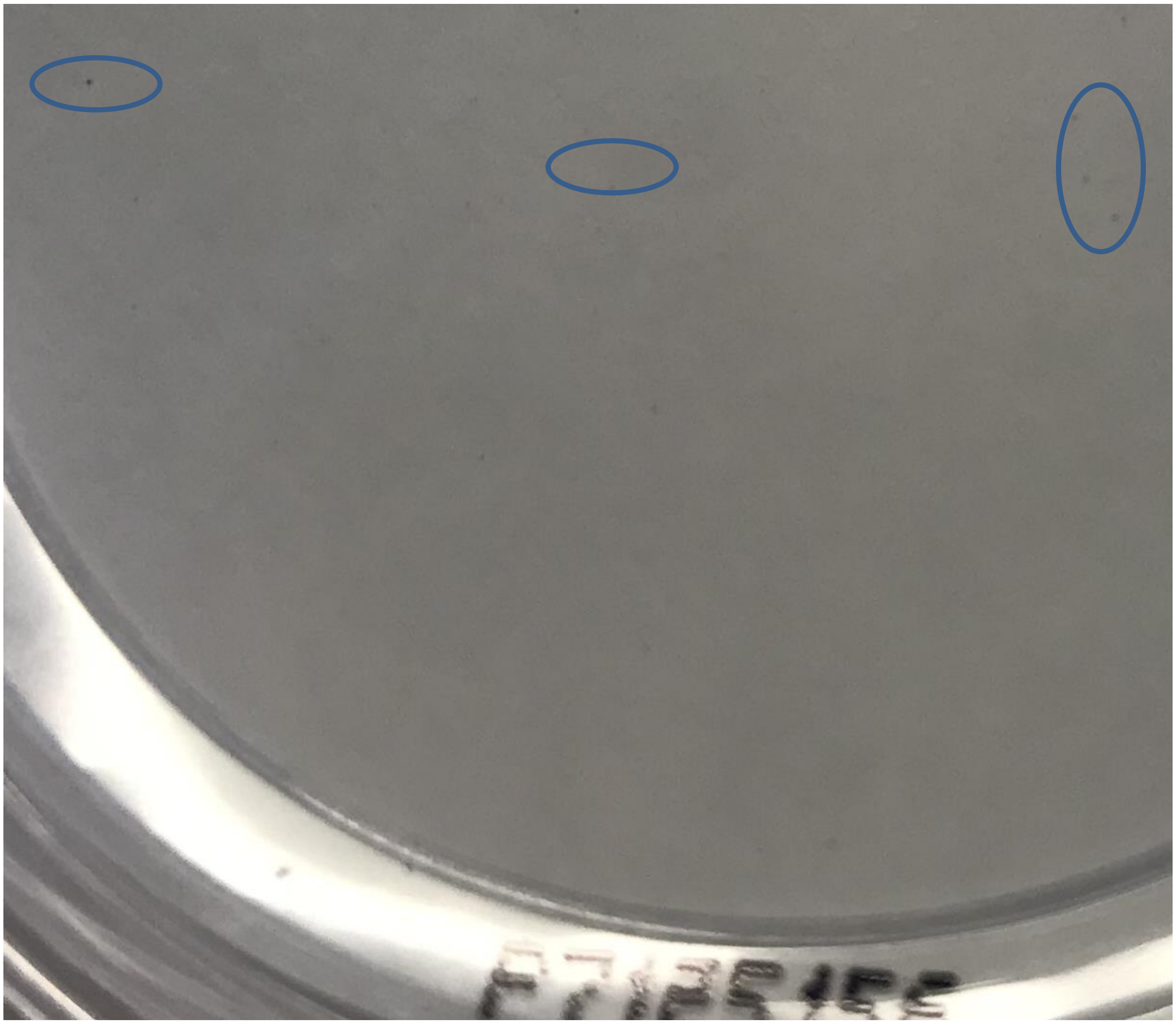


Figure C-5 Sample filter T190456 (light spotting)

Appendix D –Test Details and Data Records

This Appendix includes vessel and fuel records 1) Maintenance Records, 2) Fuel Analysis, and 3) Engine Screen Shots. These records were collected during testing.

- **Boiler records -** None provided or obtained due to the short amount of time for this testing.
- **Fuel analysis** A fuel sample was collected during our testing and sent out for analysis. The results are shown in the table below.
- **Speciated sample analysis forms.** A copy of the samples sent to the AAC and the methods utilized. Results are summarized in Appendix F.

Southwest Research Institute
6220 Culebra Road, San Antonio, TX

Test Results
Monday, January 27, 2020

Sample Description — SwRI Lab#: 51548

Test Result / Description	Units	Result, Information or Description	Rep#
SwRI Project Name		oddb	1
SwRI Lab Number		51548	1
SwRI SampleId		2193812	1
Date Sample was Received		1/15/2020 2:50:00 PM	1
SwRI Work Order Number		82758	1
SwRI Project Number		1.08.05.11.11831.01.001	1
Requested/Submitted by		bnelson	1
Sample Type		diesel	1

Client/Billing Information — SwRI Lab#: 51548

Test Result / Description	Units	Result, Information or Description	Rep#
Client Name		UNIVERSITY OF CALIFORNIA	1
Client Requestor		WAYNE MILLER	1
PO/TK Number		RT11003973	1
Primary Sponsor Code		UCR DIESEL	1

D5291 Determination of Carbon, Hydrogen — SwRI Lab#: 51548

Test Result / Description	Units	Result, Information or Description	Rep#
Carbon Content	wt%	86.82	1
Hydrogen Content	wt%	12.86	1

D4294 Sulfur by Energy-Dispersive X-Ray Flourescence — SwRI Lab#: 51548

Test Result / Description	Units	Result, Information or Description	Rep#
Sulfur by X-Ray ppm	ppm	454	1
D4294 Sulfur by Energy-Dispersive XRF	Mass %	0.045	1

Atmospheric Analysis & Consulting, Inc.

CLIENT : UC Riverside
PROJECT NAME : UCR
AAC PROJECT NO. : 191896
REPORT DATE : 11/12/2019

On November 4, 2019, Atmospheric Analysis & Consulting, Inc. received four (4) Six-Liter Summa Canisters for Fixed Gases analysis by EPA 3C. Upon receipt, the samples were assigned unique Laboratory ID numbers as follows:

Client ID	Lab No.	Return Pressure (mmHg)
10:1 Dilute w/ CFO	191896-3083	723.0
10:1 Dilute Grab Sample	191896-3084	622.0
Raw Grab Sample 1252	191896-3085	519.4
Raw Grab Sample 1257	191896-3086	565.6

This analysis is performed in accordance with AAC's Quality Manual. For detailed information pertaining to specific EPA, NCASI, ASTM and SCAQMD accreditations (Methods & Analytes), please visit our website at www.aaclab.com.

I certify that this data is technically accurate, complete, and in compliance with the terms and conditions of the contract. No problems were encountered during receiving, preparation, and/or analysis of these samples.

The Technical Director or his/her designee, as verified by the following signature, has authorized release of the data contained in this hardcopy report.

If you have any questions or require further explanation of data results, please contact the undersigned.

Sucha Parmar, Ph.D.
Technical Director

Laboratory Analysis Report

CLIENT : University of California, Riverside
PROJECT NO : 191896
UNITS : ppbC

DATE RECEIVED : 11/04/2019
DATE REPORTED : 11/08/2019

HYDROCARBONS (C1-C12) SPECIATED

Client ID	Raw Grab Sample			Sample Reporting Limit (SRL) (MRLxDF's)	Raw Grab Sample			Sample Reporting Limit (SRL) (MRLxDF's)	Method Reporting Limit (MRL)
AAC ID	191896-3085				191896-3086				
Date Sampled	10/24/2019				10/24/2019				
Date Analyzed	11/07/2019				11/07/2019				
Can Dilution Factor	1.97				1.79				
	Result	Qualifier	Analysis DF		Result	Qualifier	Analysis DF		
Ethylene	<SRL	U	1.0	1.97	<SRL	U	1.0	1.79	1.0
Acetylene	<SRL	U	1.0	1.97	<SRL	U	1.0	1.79	1.0
Ethane	<SRL	U	1.0	1.97	<SRL	U	1.0	1.79	1.0
Propylene	<SRL	U	1.0	1.97	<SRL	U	1.0	1.79	1.0
Propane	<SRL	U	1.0	1.97	<SRL	U	1.0	1.79	1.0
Isobutane	<SRL	U	1.0	1.97	<SRL	U	1.0	1.79	1.0
1-Butene	<SRL	U	1.0	1.97	<SRL	U	1.0	1.79	1.0
1,3-Butadiene	<SRL	U	1.0	1.97	<SRL	U	1.0	1.79	1.0
n-Butane	<SRL	U	1.0	1.97	<SRL	U	1.0	1.79	1.0
trans-2-Butene	<SRL	U	1.0	1.97	<SRL	U	1.0	1.79	1.0
cis-2-Butene	<SRL	U	1.0	1.97	<SRL	U	1.0	1.79	1.0
Isopentane	<SRL	U	1.0	1.97	<SRL	U	1.0	1.79	1.0
1-Pentene	<SRL	U	1.0	1.97	<SRL	U	1.0	1.79	1.0
n-Pentane	<SRL	U	1.0	1.97	2.04		1.0	1.79	1.0
Isoprene	<SRL	U	1.0	1.97	<SRL	U	1.0	1.79	1.0
trans-2-Pentene	<SRL	U	1.0	1.97	<SRL	U	1.0	1.79	1.0

Appendix E –Exhaust Flow

The calculation follows EPA Method 2 which utilizes a type S Pitot tube is used to measure the differential pressure between the counter-flow (static pressure) and parallel-flow (dynamic pressure) directions. Velocity is calculated using Bernoulli's principle, which states that the pressure in a stream of fluid is reduced as the speed of the flow is increased. The velocity calculation is based off of the temperature, molecular weight of the exhaust gas, static pressure, dynamic pressure, and relative humidity. Measurement of the differential pressure and temperature were repeated at the sampling site several times at different depths inside the duct, including the near side of the duct, in the middle of the duct, and the far side of the duct. The equation below is from the EPA Method 2 documents Equation 2-7 and 2-8.

$$V_s = K_p\, C_p \left[\frac{\sum_{i=1}^{n} \sqrt{\Delta p_i}}{n}\right] \sqrt{\frac{T_{s(abavg)}}{P_s\, M_s}} \qquad .Q = 3600(1 - B_{ws}) v_s A \left[\frac{T_{std} P_s}{T_{s(abavg)} P_{std}}\right]$$

Where:

- A = Cross-sectional area of stack, m2 (ft2).
- Bws = Water vapor in the gas stream
- Cp = Pitot tube coefficient, dimensionless.
- K = 0.127 mm H2O (metric units). 0.005 in. H2O (English units).
- Kp = Velocity equation constant.
- Ms = Molecular weight of stack gas, wet basis, g/g-mole (lb/lb-mole).
- n = Total number of traverse points.
- Pg = Stack static pressure, mm Hg (in. Hg).
- Ps = Absolute stack pressure (Pbar + Pg), mm Hg (in. Hg),
- Pstd = Standard absolute pressure, 760 mm Hg (29.92 in. Hg).
- Qsd = Dry volumetric stack gas flow rate corrected to standard conditions, dscm/hr (dscf/hr).
- Ts(abavg) = Average absolute stack temperature, °K (°R).
- Ts = Stack temperature, °C ((°deg;F).
- Tstd = Standard absolute temperature, 293 °K (528 °R).
- Vs = Average stack gas velocity, m/sec (ft/sec).
- Δp = Velocity head of stack gas, mm H2O (in. H20).
- Δpi = Individual velocity head reading at traverse point "i", mm (in.) H2O.
- Δpstd = Velocity head measured by the standard pitot tube, cm (in.) H2O.
- Δps = Velocity head measured by the Type S pitot tube, cm (in.) H2O.

Table E-1 Summary of direct measurements from the pitot tube sampling

				Average Pitot DelP			Average Pitot Static P			
Stack Diam mm	Traverse Side B	Time Start (HH:MM)	Load	(inH20)	(mmH20)	(mmH20) ^0.5	(inH20)	(mmH20)	(mmH20) ^0.5	Temp (C)
1098.54	Full	8:16	High	0.11	2.90	1.70	0.40	10.11	0.74	223
1098.54	Mid	8:26	High	0.12	3.09	1.76	0.44	11.27	0.83	225
1098.54	Shallow	8:34	High	0.10	2.54	1.59	0.37	9.36	0.69	220

Appendix F –Raw Data and Analysis

The summary results in this Appendix include raw data used to generate the values in the report including outside laboratory results. The tables of data show the results for boiler for gaseous and PM emissions. The boiler toxic emissions are also listed below. The EC/OC results were sent to an outside laboratory and were analyzed using the NIOSH thermal optical method.

There were only three test points sampled during this testing. As discussed in Section 2.5, the data needed correction due to good engineering judgement that the full sample was not stable. The gray data represents the corrected data (“adjusted”) and the non-gray data in Tables F-1 through F-3 are the original data samples so one can see the impact.

Table F-1 emissions data per test point for the original data and the “adjusted” data (gray).

Date	Project Name	Fuel	ATS	Location	Test Mode	Start Time	Sample Duration	DR	Boiler Load	Fuel Rate cacl OEM	Fuel Rate calc Meas	Fuel Rate Used Calcs	Exh Temp	Filter Temp	Stack Pres	Carb. Bal. Exh Flow I		Measured Meth2 Exh Flow II		Exh Flow Utilized
mm/dd/yyyy	name					hh:mm:ss	min	n/a	Name	kg/hr	kg/hr	kg/hr	C	C	mbar	(scfm)	(m3/hr)	(scfm)	(m3/hr)	m3/hr
10/24/2019	Tanker Boiler Test	MGO	n/a	original	1_1	10:40:00	40.3	7.0	65%	2494.8	2438.1	2438.1	221.8	41.5	0.75	17211	36467	16820	35639	35639
10/24/2019	Tanker Boiler Test	MGO	n/a	original	1_2	12:28:00	27.0	7.0	65%	2494.8	1982.4	1982.4	221.8	42.8	0.91	21167	44849	16820	35639	35639
10/24/2019	Tanker Boiler Test	MGO	n/a	original	1_3	13:44:00	43.0	7.0	65%	2494.8	2516.8	2516.8	221.8	43.6	0.53	16672	35327	16820	35639	35639
10/24/2019	Tanker Boiler Test	MGO	n/a	adjusted	1_1	11:50:00	15.0	7.0	65%	2494.8	2425.1	2425.1	221.8	41.5	0.75	17303	36663	16820	35639	35639
10/24/2019	Tanker Boiler Test	MGO	n/a	adjusted	1_2	12:28:00	10.0	7.0	65%	2494.8	2414.5	2414.5	221.8	42.8	0.91	17379	36824	16820	35639	35639
10/24/2019	Tanker Boiler Test	MGO	n/a	adjusted	1_3	14:08:52	15.0	7.0	65%	2494.8	2541.7	2541.7	221.8	43.6	0.53	16509	34981	16820	35639	35639

Table F-2 emissions data per test point for the original data and the “adjusted” data (gray). (g/hr basis)

Date	Test Group	ATS	Test	Start Time	Boiler Load	g/hr													FuelRate Carb.	SO2 calc	H20 Fraction	dil O2 Conc
mm/dd/yyyy	n/a	n/a	#	hh:mm:ss	%	NOx	CO	CO2	meas. SO_2	calc. SO_2	PM2.5	PM_EC	PM_OC	PM_S	PM_TC	PM_OCcor	PM_TCcor	PM_eBC	(kg/hr)	g/hr	%	%
10/24/2019	original	n/a	1_1	10:40:00	65%	6,475	290.20	7,377,801	761.2	2,299.9	52.8	-	-	-	-	-	-	14.16	2,438	2299.9	1.3	18.6
10/24/2019	original	n/a	1_2	12:28:00	65%	5,368	191.00	5,997,762	1,565.0	1,870.1	58.3	-	-	-	-	-	-	4.30	1,982	1870.1	1.0	15.1
10/24/2019	original	n/a	1_3	13:44:00	65%	7,883	0.00	7,616,652	2,303.3	2,374.2	60.7	-	-	-	-	-	-	1.00	2,517	2374.2	1.3	18.6
10/24/2019	adjusted	n/a	1_1	11:50:00	65%	6,686	234.0	7,338,369	444.1	2,287.6	42.1	-	-	-	-	-	-	3.4	2,425	2287.6	1.3	17.7
10/24/2019	adjusted	n/a	1_2	12:28:00	65%	6,677	230.1	7,306,291	479.0	2,277.6	57.4	-	-	-	-	-	-	3.4	2,414	2277.6	1.3	17.7
10/24/2019	adjusted	n/a	1_3	14:08:52	65%	7,790	0.0	7,692,020	604.1	2,397.6	61.6	-	-	-	-	-	-	1.9	2,542	2397.6	1.3	17.7

Table F-3 emissions data per test point for the original data and the “adjusted” data (gray). (g/kg-hr basis)

Date	Fuel	ATS	Test	Start Time	Boiler Load	g/kg-fuel (kg/tonne-fuel)													Calculated Fuel Usag			NOx Cor.
mm/dd/yyyy	n/a	n/a	#	hh:mm:ss	%	NOx	CO	CO2	meas. SO_2	calc. SO_2	PM2.5	PM_EC	PM_OC	PM_S	PM_TC	PM_OCcor	PM_TCcor	PM_eBC	Ship FC	Carb. FC	-	Kh
10/24/2019	original	n/a	1_1	10:40:00	65%	2.66	0.12	3026	0.312	0.943	0.022	-	-	-	-	-	-	0.0058	2494.8	2438	-	-
10/24/2019	original	n/a	1_2	12:28:00	65%	2.71	0.10	3025	0.789	0.943	0.029	-	-	-	-	-	-	0.0022	2494.8	1982	-	-
10/24/2019	original	n/a	1_3	13:44:00	65%	3.13	0.00	3026	0.915	0.943	0.024	-	-	-	-	-	-	0.0004	2494.8	2517	-	-
10/24/2019	adjusted	n/a	1_1	11:50:00	65%	2.76	0.10	3026	0.183	0.943	0.017	-	-	-	-	-	-	0.0014	2494.8	2425	-	-
10/24/2019	adjusted	n/a	1_2	12:28:00	65%	2.77	0.10	3026	0.198	0.943	0.024	-	-	-	-	-	-	0.0014	2494.8	2414	-	-
10/24/2019	adjusted	n/a	1_3	14:08:52	65%	3.06	0.00	3026	0.238	0.943	0.024	-	-	-	-	-	-	0.0007	2494.8	2542	-	-

Table F-4 Average for all gaseous and PM species (g/hr and g/kg-fuel)

		Average Species													Average Calculated Fuel Usag		
Units	Load	NOx	CO	CO2	meas. SO_2	calc. SO_2	PM2.5	PM_EC	PM_OC	PM_S	PM_TC	PM_OCcor	PM_TCcor	PM_eBC	Ship FC	Carb. FC	-
g/hr	65%	7051	155	7445560	509.07	2320.96	53.70	_	_	_	_	_	_	2.89	2460	2320.96	
g/kg-fuel	65%	2.86	0.06	3026.1	0.21	0.94	0.02	-	-	-	-	-	-	0.0012	2495	2460.41	

Table F-5 Standard deviation (1 sigma) for all gaseous and PM species (g/hr and g/kg-fuel)

		Stdev Species													Average Calculated Fuel Usag		
Units	Load	NOx	CO	CO2	meas. SO_2	calc. SO_2	PM2.5	PM_EC	PM_OC	PM_S	PM_TC	PM_OCcor	PM_TCcor	PM_eBC	Ship FC	Carb. FC	-
g/hr	65%	0.26	0.06	0.43	0.32	0.00	0.00	-	-	-	-	-	-	0.0028	0.00	288.50	
g/kg-fuel	65%	0.18	0.06	0.16	0.03	0.00	0.00	-	-	-	-	-	-	0.0004	0.00	70.60	

Table F-6 Summary of results EPA 3C analysis and the selected speciated hydrocarbons

Analyte	Stack EPA 3C		
	#1	#2	Ave
Dilution Factor	1.97	1.79	1.88
H2	<2.0%	<1.8%	<1.8%
Ar/O2	7.5%	7.5%	7.5%
N2	82.0%	82.0%	82.0%
CO	<0.2%	<0.2%	<0.2%
CO2	10.4%	10.5%	10.5%
CH4	<0.2%	<0.2%	<0.2%
1,3 Butadiene (ppbC)	<SRL	<SRL	<SRL
Total PAMS (ppbC)	1.99	2.04	2.02
TNMHC (ppbC)	309	189	249

Table of selected speciated HCs

Analyte	Conc. ppb	mg/kg-fuel
1,3-Butadiene	<SRL	< 0.00907
Benzene	<SRL	< 0.00874
Toluene	<SRL	< 0.00883
m/p-Xylenes	<SRL	< 0.00891
Ethylbenzene	<SRL	< 0.00891
o-Xylene	<SRL	< 0.00891
Total PAMS	2.02	0.00332
TNMHC	249.0	0.516

Table F-7 Detail of the raw suma canister samples speciated HC (C2-C12) results. All values but two are below the detection limit (SRL)

Analyte	MM_C1	Formula	Raw (ppb)		mg/kg-fuel	Analyte	MM	Formula	Raw (ppb)		mg/kg-fuel
			ID#1	ID#2					ID#1	ID#2	
Ethylene	14.0	C2H4	<SRL	<SRL	< 0.00941						
Acetylene	13.0	C2H2	<SRL	<SRL	< 0.00874	3-Methylhexane	14.3	C7H16	<SRL	<SRL	< 0.00961
Ethane	15.0	C2H6	<SRL	<SRL	< 0.01009	2,2,4-Trimethylpentane	14.3	C8H18	<SRL	<SRL	< 0.00958
Propylene	14.0	C3H6	<SRL	<SRL	< 0.00941	n-Heptane	14.3	C7H16	<SRL	<SRL	< 0.00961
Propane	14.7	C3H8	<SRL	<SRL	< 0.00986	Methylcyclohexane	14.0	C7H14	<SRL	<SRL	< 0.00941
Isobutane	14.5	C4H10	<SRL	<SRL	< 0.00975	2,3,4-Trimethylpentane	14.3	C8H18	<SRL	<SRL	< 0.00958
1-Butene	14.0	C4H8	<SRL	<SRL	< 0.00941	Toluene	13.2	C7H8	<SRL	<SRL	< 0.00883
1,3-Butadiene	13.5	C4H6	<SRL	<SRL	< 0.00907	2-Methylheptane	14.3	C8H18	<SRL	<SRL	< 0.00958
n-Butane	14.5	C4H10	<SRL	<SRL	< 0.00975	3-Methylheptane	14.3	C8H18	<SRL	<SRL	< 0.00958
trans-2-Butene	14.0	C4H8	<SRL	<SRL	< 0.00941	n-Octane	14.3	C8H18	<SRL	<SRL	< 0.00958
cis-2-Pentane	14.0	C5H10	<SRL	<SRL	< 0.00941	Ethylbenzene	13.3	C8H10	<SRL	<SRL	< 0.00891
Isopentane	14.4	C5H12	<SRL	<SRL	< 0.00968	m/p-Xylenes	13.3	C8H10	<SRL	<SRL	< 0.00891
1-Pentene	14.0	C5H10	<SRL	<SRL	< 0.00941	Styrene	13.0	C8H8	<SRL	<SRL	< 0.00874
n-Pentane	14.4	C5H12	<SRL	2.04	0.00968	o-Xylene	13.3	C8H10	<SRL	<SRL	< 0.00891
Isoprene	13.6	C5H8	<SRL	<SRL	< 0.00914	Nonane	14.3	C9H20	1.99	<SRL	0.00966
trans-2-Pentene	14.0	C5H10	<SRL	<SRL	< 0.00941	Isopropylbenzene	13.4	C9H12	<SRL	<SRL	< 0.00896
cis-2-Pentene	14.0	C5H10	<SRL	<SRL	< 0.00941	.alpha.-Pinene	13.6	C10H16	<SRL	<SRL	< 0.00914
2,2-Dimethylbutane	14.4	C6H14	<SRL	<SRL	< 0.00964	n-Propylbenzene	13.4	C9H12	<SRL	<SRL	< 0.00896
Cyclopentane	14.0	C5H10	<SRL	<SRL	< 0.00941	m-Ethyltoluene	13.4	C9H12	<SRL	<SRL	< 0.00896
2,3-Dimethylbutane	14.4	C6H14	<SRL	<SRL	< 0.00964	p-Ethyltoluene	13.4	C9H12	<SRL	<SRL	< 0.00896
2-Methylpentane	14.4	C6H14	<SRL	<SRL	< 0.00964	1,3,5-Trimethylbenzene	13.4	C9H12	<SRL	<SRL	< 0.00896
3-Methylpentane	14.4	C6H14	<SRL	<SRL	< 0.00964	o-Ethyltoluene	13.4	C9H12	<SRL	<SRL	< 0.00896
1-Hexene	14.0	C6H12	<SRL	<SRL	< 0.00941	.beta.-Pinene	13.6	C10H16	<SRL	<SRL	< 0.00914
n-Hexane	14.4	C6H14	<SRL	<SRL	< 0.00964	1,2,4-Trimethylbenzene	13.4	C9H12	<SRL	<SRL	< 0.00896
Methylcyclopentane	14.0	C6H12	<SRL	<SRL	< 0.00941	n-Decane	14.2	C10H22	<SRL	<SRL	< 0.00955
2,4-Dimethylpentane	14.3	C7H16	<SRL	<SRL	< 0.00961	1,2,3-Trimethylbenzene	13.4	C9H12	<SRL	<SRL	< 0.00896
Benzene	13.0	C6H6	<SRL	<SRL	< 0.00874	m-Diethylbenzene	13.4	C10H14	<SRL	<SRL	< 0.00901
Cyclohexane	14.0	C6H12	<SRL	<SRL	< 0.00941	p-Diethylbenzene	13.4	C10H14	<SRL	<SRL	< 0.00901
2-Methylhexane	14.3	C7H16	<SRL	<SRL	< 0.00961	n-Undecane	14.2	C11H24	<SRL	<SRL	< 0.00954
2,3-Dimethylpentane	14.3	C7H16	<SRL	<SRL	< 0.00961	n-Dodecane	14.2	C12H26	<SRL	<SRL	< 0.00953
Total PAMS	14.70	C3H8	1.99	2.04	0.00332						
TNMHC	14.70	C3H8	309	189	0.516						