Final Report

TRL Definitions for Oil Spill Response Technologies and Equipment

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Report For

U.S. Department of the Interior
Bureau of Safety and Environmental Enforcement (BSEE)
Sterling, VA

January 2016

This study was funded by the Bureau of Safety and Environmental Enforcement (BSEE), U.S. Department of the Interior, Washington, D.C., under Contract Number E14PC00020.

ACKNOWLEDGMENTS

The authors wish to thank the Ohmsett staff for their assistance preparing and implementing the Workshop as well as all the participants. Mike Brennan was especially helpful in gaining access for the attendees.

DISCLAIMER

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EXECUTIVE SUMMARY

The goal of this project was to develop the BSEE Technology Readiness Levels (TRLs) for Oil Spill Response Technologies and Equipment to enable the oil spill response community to objectively classify the various oil spill response tools and technologies under development now and in the future. Our goal was achieved through a series of meetings, teleconference calls, and a two day workshop at the Ohmsett Test Facility on October 21 and 22, 2015. Twenty four people attended the workshop from a broad spectrum of the oil spill response community including Government agencies, Non-Governmental organizations, non-profit organizations, technology providers, large oil exploration and production corporations, oil spill response organizations, and those who operate oil spill testing facilities. The group worked to come to agreement on 9 TRLs, ranging from TRL 1 where basic research begins to transition to applied research, and culminating in TRL 9 where the technology is deployed to mitigate an oil spill in a real spill environment. The 9 TRLs are shown in Table 1.

Table 1. BSEE Oil Spill Response TRLs

TRL	Title
Technology Research and Development	
1	Basic principles observed or reported
2	Technology concept and speculative application formulated
3	Technology proof of concept demonstrated
Technology Advancement, Development, and Demonstration	
4	Technology prototype demonstrated in laboratory environment or model scenario
5	Technology prototype tested in relevant environments
6	Full scale prototype demonstrated in relevant environments
Technology Implementation in Operational Environments	
7	Integrated technology tested on a large scale or in open water
8	Final integrated system tested in real or relevant environment
Technology Deployment in Real Spill Environment	
9	Final integrated system deployed in real spill environment

As part of this work we categorized several of the oil spill test facilities and matched them with various spill environments. In that process we identified a deficiency in test facilities for aerial applications and in facilities for study at the high pressures and low temperatures characteristic of deepwater blowouts. There are few facilities with more than 3 test environments and no facility for simultaneous control of depth, current, and the open space of the deep ocean.

Based on our findings and numerous discussions it was suggested that implementation of the TRLs would be simplified if a web based TRL "calculator" was created. The TRL calculator could use series of questions to automatically and unambiguously determine the TRL for a given technology. Additional granularity for the TRLs similar to the Department of Energy Marine and Hydrokinetic TRLs would also be useful for helping the community understand and use the TRLs. It would also be useful to classify and compile the specifications of the various test facilities around the world and match them to various spill environments in more depth. In addition, more specific definitions of the spill environments would help the community understand which technologies to deploy for a given spill and where to focus during technology development. Another useful application of the TRLs would be to categorize the database of projects on the BSEE website to include the TRLs so that people looking for specific technologies at specific TRLs could easily find them.

1. OBJECTIVE

The objective of this project was to develop the BSEE Technology Readiness Levels (TRLs) for Oil Spill Response Technologies and Equipment to enable the oil spill response community to objectively classify the various oil spill response tools and technologies under development now and in the future.

2. OVERVIEW

Technology Readiness Levels (TRLs) have been extensively used in the aerospace community, the petroleum industry, the Department of Energy (DOE), and by the Department of Defense (DOD) to accurately categorize the maturity of scientific ideas and technologies. The TRLs provide a uniform and objective means to determine if and when a new technology is ready for use in the field. They also help to identify levels of confidence and risks associated with introducing new technologies. While technology readiness levels exist for many agencies, none of them were directly applicable to the oil spill response technologies. To help overcome this deficiency we formed an organizing committee to help guide the project and come up with the first draft of TRLs, assemble a working group, and plan a workshop. The working group consisted of people from around the world who are involved in oil spill response technology development, assessment, funding, and deployment. Participants in the working group represented Government agencies, Non-Governmental organizations, non-profit organizations, technology providers, major oil companies, oil spill response organizations, as well as people who help operate oil spill testing facilities. The rest of this report summarizes our findings and provides a detailed description of the TRLs developed by the team.

3 TRLS IN OTHER ORGANIZATIONS AND AGENCIES

Technology Readiness Levels (TRLs) have been extensively used in the aerospace community, the petroleum industry, the Department of Energy (DOE), and by the Department of Defense (DOD) to accurately categorize the maturity of scientific ideas and technologies. The TRLs provide a uniform and objective means to determine if and when a new technology is ready for use in the field. They also help to identify levels of confidence and risks associated with introducing new technologies. The TRLs adopted by the Oil and Gas industry for subsurface technologies are shown in Table 2. The National Aeronautics and Space Administration (NASA), The European Space Agency (ESA), DOD, and DOE TRLs are shown in Table 3 through Table 5 respectively. The TRLs for NASA and the DOD are nearly identical with the exception of TRL 9 where NASA has the added work "flight". Due to the extreme similarity between NASA and DOD TRLs we will refer to them as the same and call them the NASA/DOD TRLs.

There are key similarities and differences between the NASA/DOD, DOE and the oil and gas TRLs with the numbering system being the most obvious difference. Less obvious differences are in the descriptions, where the oil and gas TRLs specifies “simulated environment,” “intended environment,” and “intended operating system” instead of NASA/DOD and DOE which specify “relevant environment” and “operational environment.” While these differences are noteworthy, overall the concept is the same in that basic scientific exploration and proof of concept reside at the low TRLs where scientists are asking the question, “Does the biology, chemistry, or work?” These basic technology research studies usually take place in academic institutions, government labs, or industrial research labs. Once past the Technology Research and Development levels in TRL 1 through TRL 3 the technologies move into the Technology Demonstration Levels (TRL 4 through TRL 6). These demonstration levels can further be subdivided into measurements in the lab and measurements in relevant or simulated environments.

The Technology Transfer where the scientific or technical capabilities advance into marketable goods or services, takes place in the later TRLs (TRL 7 through 9) where engineers work to harden the technologies and make them able to withstand operational environments. To advance through these levels the technology needs to go through several iterations of refinement to improve the functionality, fidelity, user interface, and other operational characteristics to become useful and usable by a non-expert. Key to the advancement through the TRLs is access and availability of relevant environments that simulate the pertinent conditions of the operational environment.

Table 2 TRL definitions developed for the oil and gas industry [1].

Oil and Gas Technology Readiness Levels	
TRL	**Description**
0. Unproven idea/proposal	Paper concept. No analysis or testing has been performed
1. Concept demonstrated	Basic functionality demonstrated by analysis, reference to features shared with existing technology or through testing on individual subcomponents/subsystems. Shall show that the technology is likely to meet specified objectives with additional testing
2. Concept validated	Concept design or novel features of design validated through model or small scale testing in **laboratory environment**. Shall show that the technology can meet specified acceptance criteria with additional testing
3. New technology tested	Prototype built and functionality demonstrated through testing over a **limited range of operating conditions.** These tests can be done on a scaled version if scalable
4. Technology qualified for first use	Full-scale **prototype built** and technology qualified through testing in **intended environment, simulated** or actual. The new hardware is now ready for first use
5. Technology integration tested	Full-scale prototype built and integrated into **intended operating system** with full interface and functionality tests
6. Technology installed	Full-scale prototype built and integrated into **intended operating system** with full interface and functionality test program in **intended environment**. The technology has shown acceptable performance and reliability over a period of time
7. Proven technology	Technology integrated into **intended operating system**. The technology has successfully operated with acceptable performance and reliability within the **predefined criteria**

Table 3 Technology Readiness Levels in NASA and the ESA [2,3]

TRL Level	Description
TRL 1	Basic principles observed and reported
TRL 2	Technology concept and/or application formulated
TRL 3	Analytical and experimental critical function and/or characteristic proof-of concept
TRL 4	Component and/or breadboard validation in laboratory environment
TRL 5	Component and/or breadboard validation in relevant environment
TRL 6	System/subsystem model or prototype demonstration in a relevant environment (ground or space)
TRL 7	System prototype demonstration in a space environment
TRL 8	Actual system completed and "flight qualified" through test and demonstration (ground or space)
TRL 9	Actual system "flight proven" through successful mission operations

Table 4 Technology Readiness Levels in the DOD[4]

Level	DOD TRL Definition*
1	Basic principles observed and reported
2	Technology concept and/or application formulated
3	Analytical and experimental critical function and/or characteristic proof of concept
4	Component and/or breadboard validation in laboratory environment
5	Component and/or breadboard validation in relevant environment
6	System/subsystem model or prototype demonstration in relevant environment
7	System prototype demonstration in operational environment
8	Actual system completed and qualified through test and demonstration
9	Actual system proven in successful mission operations

* Source: DOD 2011.

Table 5 Technology Readiness Levels in the DOE[5]

Technology Readiness Level	Description
TRL 1.	Scientific research begins translation to applied R&D - Lowest level of technology readiness. Scientific research begins to be translated into applied research and development. Examples might include paper studies of a technology's basic properties.
TRL 2.	Invention begins - Once basic principles are observed, practical applications can be invented. Applications are speculative and there may be no proof or detailed analysis to support the assumptions. Examples are limited to analytic studies.
TRL 3.	Active R&D is initiated - Active research and development is initiated. This includes analytical studies and laboratory studies to physically validate analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.
TRL 4.	Basic technological components are integrated - Basic technological components are integrated to establish that the pieces will work together.
TRL 5.	Fidelity of breadboard technology improves significantly - The basic technological components are integrated with reasonably realistic supporting elements so it can be tested in a simulated environment. Examples include "high fidelity" laboratory integration of components.
TRL 6.	Model/prototype is tested in relevant environment - Representative model or prototype system, which is well beyond that of TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in simulated operational environment.
TRL 7.	Prototype near or at planned operational system - Represents a major step up from TRL 6, requiring demonstration of an actual system prototype in an operational environment.
TRL 8.	Technology is proven to work - Actual technology completed and qualified through test and demonstration.
TRL 9.	Actual application of technology is in its final form - Technology proven through successful operations.

Table 6 Relationship between the various TRLs

API TRL #	NASA/DOD/DOE/ESA TRL #
0	1
1	2,3
2	4
3	5
4	6
5	6,7
6	8
7	9

4. BSEE OIL SPILL RESPONSE TECHNOLOGY READINESS LEVELS

During the project we held a series of meetings at technical conferences, teleconference calls, and a working group meeting. Twenty four people attended the working group meeting at the Ohmsett test facility in Leonardo, NJ on October 21 and 22, 2015. During Workshop we further developed the TRLs, provided examples of TRLs and begun using the TRLs to classify oil spill response technologies. In the discussion that follows the words technology and technique can be used interchangeably.

During the Workshop an overview of TRLs was provided and several experts presented the state-of-the-art of various oil spill technologies. These presentations included examples of the lower TRL projects, where scientific exploration occurs and applied research begins, as well as examples of technologies that had progressed through the full range of TRLs. These technologies include acoustic measurements of oil droplet size, In-Situ Burning (ISB), boom and skimmers, and dispersant applications. The development of herding agents for ISB provided a detailed example for how a technology progressed through each TRL. The working group observed a demonstration of a commercial skimmer to illustrate the importance of testing within relevant operating environments, and large scale testing of dispersants to illustrate the challenges of achieving different TRLs.

4.1 SUMMARY TABLE OF BSEE OIL SPILL RESPONSE TRLS

The final TRLs developed throughout the process are summarized in Table 7 in an abbreviated form. There are nine TRLs in 4 basic categories that describe the advancement from basic idea in TRL 1 to a technology that has been deployed on intentional release or unintentional spill and successfully met the performance and operational specifications defined in earlier TRLs.

Table 7. BSEE Oil Spill Response Technology Readiness Levels

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

4.2 Detailed Description of BSEE Oil Spill Response TRLs

A more detailed description of each TRL is discussed below. For key TRLs, Stage Gates are described. These Stage Gates are general accomplishments that must be achieved before a technology can be classified at or above a certain TRL.

TRL 1 to TRL 3: Technology Research and Development

TRL 1. Basic principles observed and reported

Basic scientific exploration of relevant biology, chemistry, or physics begins and leads to enhanced knowledge for a relevant subject area. One or more unproven ideas have been formulated that warrant transition to applied research related to oil spill response. No analysis or experiments have been performed and the unproven ideas may be paper concepts.

Stage Gate to achieve TRL 1:

- The relevant science has been identified.
- An idea has been formulated for transition to applied research.

TRL 2. Technology concept and speculative application formulated

The technology concept has been formulated and the potential broad class of spill response applications has been identified. The viability and feasibility of technology concept has been considered. Limited experimentation has occurred and limited or preliminary data have been generated and analyzed from experiments or computational models.

Stage Gate to achieve TRL 2:

- The basic science to support the concept has been confirmed.
- A class of spill response applications for the concept been identified.

TRL 3. Technology proof of concept demonstrated

The proof of concept of the relevant biological, chemical or physical principles or techniques has been shown on a relevant hydrocarbon product or other relevant materials. Data from a computational model has been generated for a specific scenario. The data have been reproduced and one or more products or scenarios on a laboratory scale. Individual components or algorithms are tested in a bench top setting or an ad hoc system. For theoretical and computational modeling developments, the initial algorithm has been developed and the forward calculation completed to generate data.

Stage Gate to achieve TRL 3:

- Proof of concept has been shown in a laboratory environment.
- Data has been reproduced on one or more hydrocarbon products or other relevant materials.

TRL 4 to TRL 6: Technology Advancement, Development, and Demonstration

TRL 4. Technology prototype demonstrated in laboratory environment or model scenario

A prototype of the technology has been demonstrated in a laboratory environment. The prototype is advanced over the proof of concept either by hardware, software, and/or with reproducible data generated for specific scenarios on relevant hydrocarbon products or applications. The prototype can be less than full scale. If the technology is a computational model, the model data has been compared with experimental measurements of the relevant scenario.

Stage Gate to achieve TRL 4:

- A prototype of the technology has been demonstrated in a laboratory environment.

TRL 5. Technology prototype tested in relevant environments

A prototype of the technology with increased fidelity over the proof of concept has been demonstrated in relevant environments. Accuracy and precision of the results have been documented. Separate components are acceptable if an integrated prototype is cost prohibitive. Multiple variables may be tested as well as several different hydrocarbon products in several relevant environments. If the technology is a computational model, ground truthing of model has occurred through validation with experimental data.

Stage Gate to achieve TRL 5:

- A prototype of the technology has been demonstrated in relevant environments.
- Accuracy and precision of results have been documented.

TRL 6. Full scale prototype demonstrated in relevant environments

A full scale prototype of the technology has been successfully demonstrated in relevant environments. The prototype builds on the proof of concept and is advanced either in component integration, fidelity of the hardware or software, or with experimental or model data generated for specific scenarios to show applicability. Consideration of future regulatory approvals and industry standards are included in the test plan.

Stage Gate to achieve TRL 6:

- A full scale prototype of the technology has been demonstrated in relevant environments.
- Future regulatory approvals and industry standards are included in the test plan.

TRL 7 and TRL 8: Technology Implementation in Operational Environments

TRL 7. Integrated technology tested on a large scale or in open water

Full scale prototype integrated into intended operating system and tested on a simulated spill, in a relevant environment, in open water, or in a real spill environment. Intended operator is identified and system has been beta tested by others. Where appropriate, analysis and/or interpretation have become automated and the timeliness of the results has been determined (real time or post processed). Expected performance and specifications of the technology are defined through a performance test matrix. Safety parameters for technology deployment are considered. The test protocol and procedure have been defined and a user manual is being developed

Stage Gate to achieve TRL 7:

- A full-scale and fully integrated prototype has been tested in a relevant environment or a real spill environment.
- The intended operator has been identified, and the system has been beta tested by others.
- Where appropriate, data analysis and/or interpretation have become automated.

TRL 8. Final integrated system tested in real or relevant environment

The final integrated system has been proven to function in a real or relevant environment with performance and operational specifications and limitations defined through performance and reliability testing on several scenarios and products. Reproducible data to support claims has been documented in publically available publications. As part of this level the system should be successfully used by the intended operator and is ready for spills of opportunity and field use. The user manual and training procedure have been finalized. Independent verification of data for all claims is recommended but not required. The safety parameters for technology deployment have been developed, documented, and validated through several deployments.

Stage Gate to achieve TRL 8:

- Define and test performance and operability limits.
- Data to support performance claims is publically available.
- Technology has been used by the intended operator.
- Regulatory requirements have been met.
- Safety parameters have been developed, documented and validated.

TRL 9: Technology Deployment in Real Spill Environment

TRL 9. Final integrated system deployed in real spill environment

Technology has been successfully operated on an intentional release or unintentional spill in a real spill environment by the intended operator and meets the technology performance and operational claims. Training and supporting documents including a user manual and any record of independent verification or certifications are included.

Stage Gate to achieve TRL 9:

- Successful operation of technology by intended operator in a real spill environment.
- Technology meets performance and operational claims.
- Technology met performance claims from previous TRLs.

5. CLASSIFICATION OF TECHNOLOGIES

While some are well versed in the usage of TRLs, it was found that many in the oil spill response community would benefit by seeing examples of technologies at the various TRLs. In the sections that follow we show the advancement of acoustic measurements through TRL 3 where the proof of concept to measure the mean oil droplet size was shown. We also discuss the development of the technique to apply dispersants to oil in Arctic and sub-Arctic conditions with ice to show the advancement from TRL 2 through TRL 6. We conclude the section showing the advancement of the use of herders for in-situ burning in ice from TRL 2 through TRL 8.

5.1 Low TRLs: Acoustic measurements of oil droplet size

During the beginning phases of technology development much of the research occurs in laboratory environments in scenarios that are far from reality. An example of an idea at a TRL 2 is shown in Figure 1 where the researchers were determining if acoustic measurements could be used to sense changes in oil droplet size and concentration. The potential exists because when an acoustic wave travels through oil droplets in water, the acoustic wave scatters at the oil-water interface due to the discontinuity of density and speed of sound in oil and water. The preliminary measurements were performed on crude oil and tap water with little control of droplet size or dispersant to oil ratio, using a paint mixer to provide the mixing energy. This preliminary study showed that the propagation and measurement of acoustic waves through water and oil showed sensitivity to oil droplet size and concentration. Once this basic science to support the concept had been confirmed (TRL 2), the researchers began systematic experiments shown in Figure 2 where the dispersant to oil ratio and mixing energy was controlled and reproduced. These measurements were still in the TRL 2 category because they had not yet shown the proof of concept.

15 mL Canadian Hebron Oil

1.5 mL Corexit 9500 Dispersant
Dispersant to Oil Ration (DOR) 1:2.5

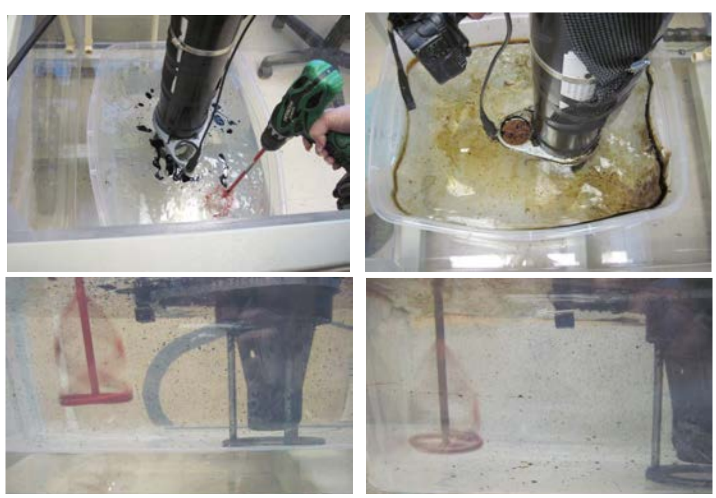

Figure 1. Initial acoustic measurements of oil droplets at TRL 2.

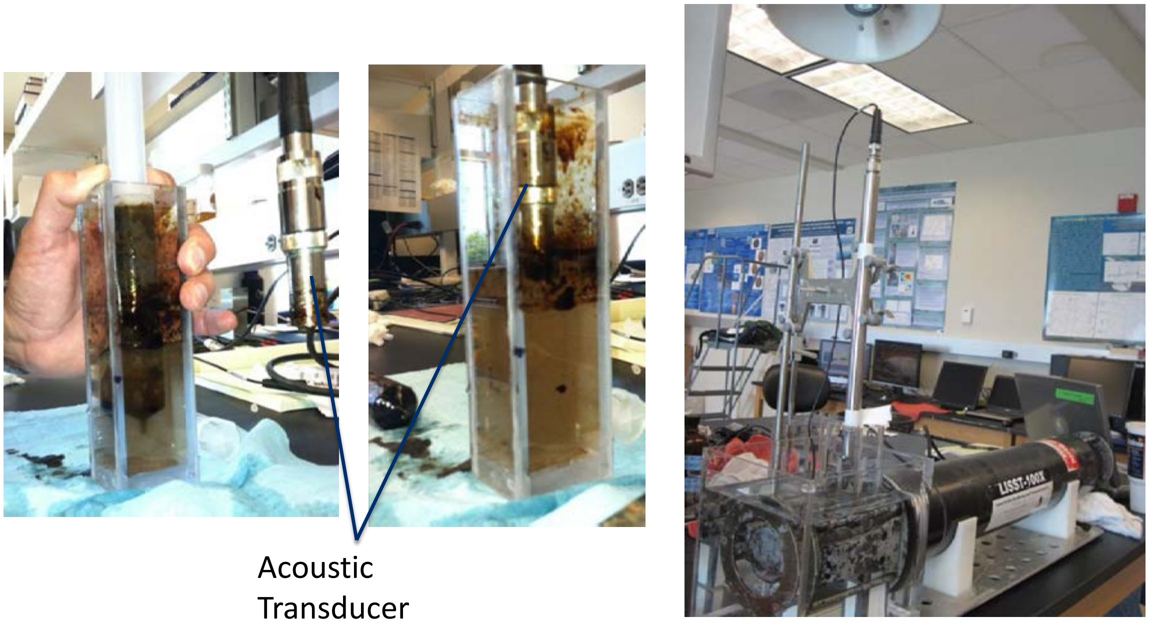

Figure 2. Controlled acoustic measurements of oil droplets and comparison with the LISST. This comparison was critical for the proof of concept testing to reach TRL 3.

To advance to a TRL 3 the acoustic data was benchmarked against the droplet size distributions from the Laser In-situ Scattering Transmissometry (LISST) instrument. The researchers performed measurements on subsurface releases of oil and dispersant in a laboratory shown in Figure 3 setting on multiple occasions and dispersant to oil ratios. The resultant proof of concept data to advance through TRL 3 is shown in Figure 4 where the mean droplet size determined from the acoustic measurements is compared with the LISST measurements [6,7].

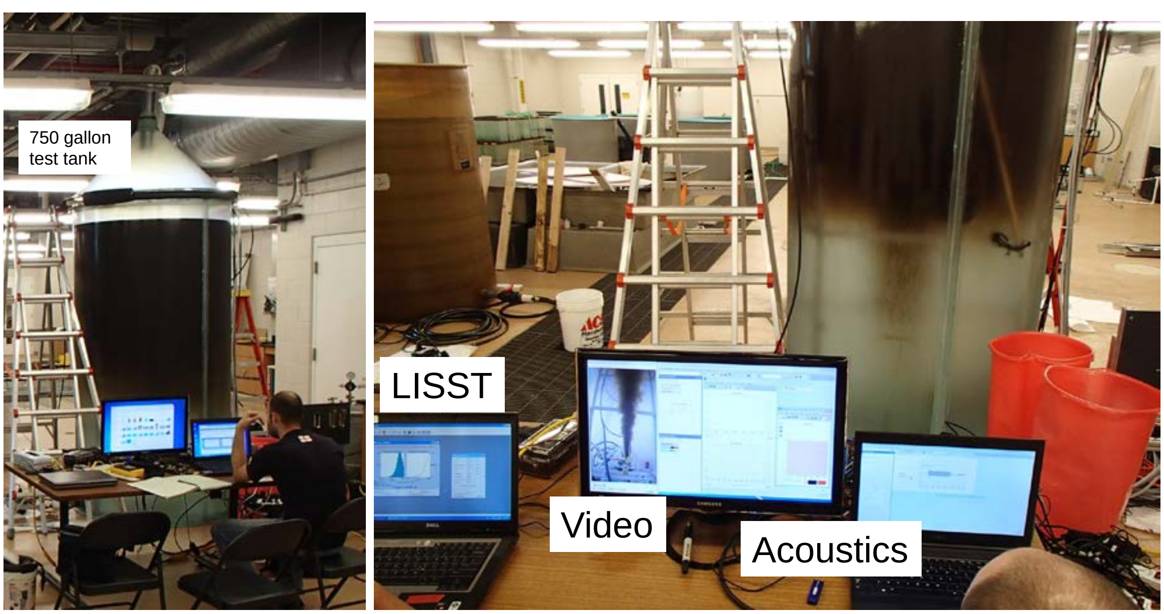

Figure 3. Subsurface releases of oil and dispersant to produce proof of concept data and achieve TRL 3.

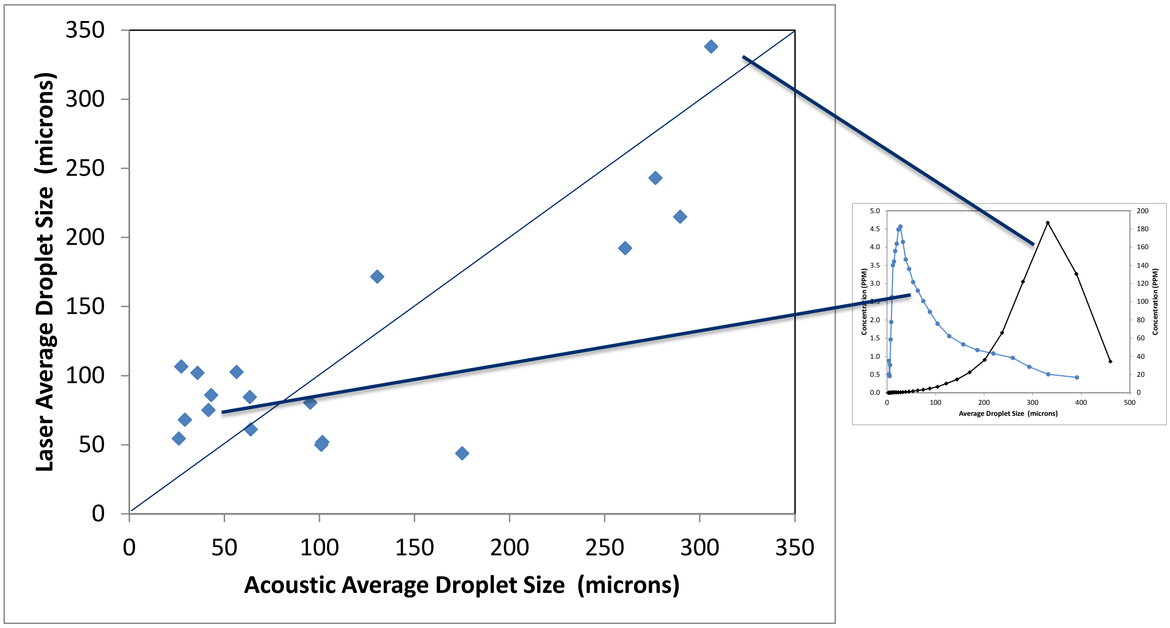

Figure 4. Proof of concept data for acoustic measurements of mean oil droplet size during TRL 3 research.

Table 8 summarizes the advancement through the TRLs. To move advance the acoustic measurements of oil droplet size distributions further we need to compare the experiments with relevant theories to quantitatively calculate the oil droplet size distribution. These measurements would need to be performed on several different oils for various dispersant to oil ratios in the lab and in relevant environments to advance to TRL 4, and above.

Table 8. Advancement of TRLs for acoustic measurement of mean oil droplet size.

Milestone	Date	TRL
Initial measurements in the lab with uncontrolled conditions	2012	2
Preliminary data with known dispersant to oil ratio and controlled mixing	2013	2
Controlled experiments on subsurface releases of oil and benchmarking of oil droplet size	2014	3

5.2 Low to Mid TRLs: Dispersant Effectiveness in Cold Water and in the Presence of Ice

Proving the effectiveness of dispersant use on oil spilled in cold water and in the presence of ice provides an example of the evolution of a technique, rather than a material or specific piece of equipment. Dispersant use on marine spills in open water with certain oils and situations has been at TRL 9 for a considerable time. However dispersants had not been tested in ice fields or under Arctic conditions, reducing the readiness of dispersant technology for this new operating environment to TRL 2. The following describes research and development to advance dispersant use in Arctic and sub-Arctic conditions from TRL 2 to TRL 6.

There has long been a general misconception that cold temperatures inhibit dispersant effectiveness. Testing dispersants in large basins at cold temperatures was instrumental in investigating dispersant effectiveness in a realistic environment. In particular, a succession of near full-scale dispersant testing at Ohmsett with various oils at Arctic and sub-Arctic water temperatures definitively showed the effectiveness of dispersants in cold conditions. Specifically, a series of tests were performed at Ohmsett in cold water between -1 and +10°C on Alaskan and east coast Canadian crude oils [8,9,10,11,12] using Corexit 9500 and 9527 dispersants. These dispersants were found to be very effective on all of the oils tested in these large outdoor test tank experiments. These tests raised the TRL for dispersant application in cold water to TRL 5 because Ohmsett is considered a relevant environment for surface application of dispersants.

The presence of ice can be an additional concern because it significantly dampens the wave field and changes the surface mixing conditions. This reduced mixing energy may be insufficient to generate and then diffuse small oil droplets once the dispersant has been applied. The presence of broken ice in concentrations above 30 to 50% Despite this lack of mixing at the micro-level, research has examined whether ice generates localized energy through its mechanical grinding and pumping actions as it rises and falls and interacts in a dampened wave field. This was first studied in tests at Esso Resources wave basin in Calgary in the 1990s [13], in which dispersant was applied to oil in a field of broken ice, with favorable results observed, raising the TRL to 4 for dispersant use in ice conditions.

Additional testing done at a larger scale at Ohmsett [14] and in a ship-testing basin [15] showed that the energy generated at the ice edges and in broken ice and slush fields is sufficient to disperse chemically treated oil, as shown in Figure 5,. The use of containment booms to direct oil to a ship's propeller turbulence to disperse treated oil in low ice concentration waters have also been investigated and shown to be a promising option [16]. These tests at full scale raised the TRL for the technique to TRL 6, and increased the integration of the dispersant systems.

Figure 5 Dispersant tests in ice: Ohmsett

In a complete ice cover condition there is insufficient natural mixing energy to generate oil dispersion once dispersant is applied since the oil may be trapped under the ice and be inaccessible to a spraying operation, see Figure 6. Tests have been performed to investigate the use of a ship's propeller wash to provide the required energy to shear the treated oil into a fine oil cloud that will diffuse throughout the water column. [16,17], see Figure 7. The use of azimuthal stern drive systems has been shown to be a promising option for applying the necessary mixing energy for a dispersant-use operation in a complete ice cover environment [15,16,17]. The oil droplets generated by the short term-intense mixing of these propellers must be small enough to remain suspended and diffuse throughout the water column under the limited natural turbulence present under the ice cover after the ship has moved on or the oil will simply rise back to the underside of the ice. The research to date has shown that oil that is chemically treated and mechanically mixed by the propeller will in fact remain suspended in the water column for considerable time.

The concept of using ship's thrusters to disperse free-drifting slicks in pack ice after they have been sprayed with dispersants was field tested on a large scale in 2009 as part of a large Joint Industry Program on Oil Spill Contingency for Arctic and Ice-covered Waters organized by SINTEF in Norway [18]. By improving the application of the dispersant and mixing energy the SINTEF tests advanced the TRL for dispersant use of dispersants in ice to TRL 6.

Figure 6 Dispersant application in dense pack ice: Barents Sea tests

Figure 7 Use of ship's propeller wash to mix oil that has been treated with dispersant

In summary, the application of dispersants to oil present at ice edges in leads or between ice floes may be a viable countermeasures option depending on the ice conditions and prevailing environmental conditions. Additional research into the amount of turbulence present under ice, the size of the oil drops required for permanent dispersal under the ice, and the drop sizes generated by this process for different oil types will be required to assess the range of conditions where this countermeasures option might be viable to advance the technique to TRL 7, 8, and 9.

Table 9. Milestones and TRLs for dispersant applications in cold water and in the presence of ice

Milestone	Date	TRL
Extensive experience with dispersant use in temperate waters	1980s, 1990s	2
Initial basin tests of dispersant to oil among ice	1996	4
Series of tests at Ohmsett in cold water	2003 to 2008	5
Large-scale tests of dispersant to oil among ice	2004 to 2007	6
Field tests in Barents Sea	2009	6

5.3 Moving Through the TRLs: Herders for In-Situ Burning (ISB) in Ice

Research and development on the use of herding agents in conjunction with ISB in ice provides an example of the evolution of a response technique with regards to TRLs as well as the time involved to move through the TRLs. Herding agents were initially developed in the 1970s as a method of thickening oil slicks prior to mechanical recovery. Unfortunately, it was discovered during field tests that herded slicks began to re-spread in tens of minutes in all but relatively calm seas. They were never applied during an actual offshore spill because mechanical recovery requires longer periods to implement. Over the last 15 years, researchers began to consider the use of herding agents for ISB, particularly for oil spilled in drift ice conditions. Because herding agents had not been used to support ISB operations nor in the drift ice environment, this new technique was at a lower TRL than using herders for mechanical recovery.

Starting in 2003, lab tests demonstrated that herding agents persisted long enough to enable in-situ burning of relatively fresh, fluid oils in broken or drift ice. Initial tests were small-scale (approximately 1 m^2), and assessed a shoreline-cleaning agent with oil herding properties (Figure 8). Tests examined its ability to herd different oils on cold water and among ice [19]. Prior to this study, herders were at a TRL 2 because basic scientific research had already been conducted that provided preliminary support for the new and untested application in drift ice. These small-scale tests advanced herder applications for ISB in drift ice to TRL 3 by demonstrating the proof of the concept.

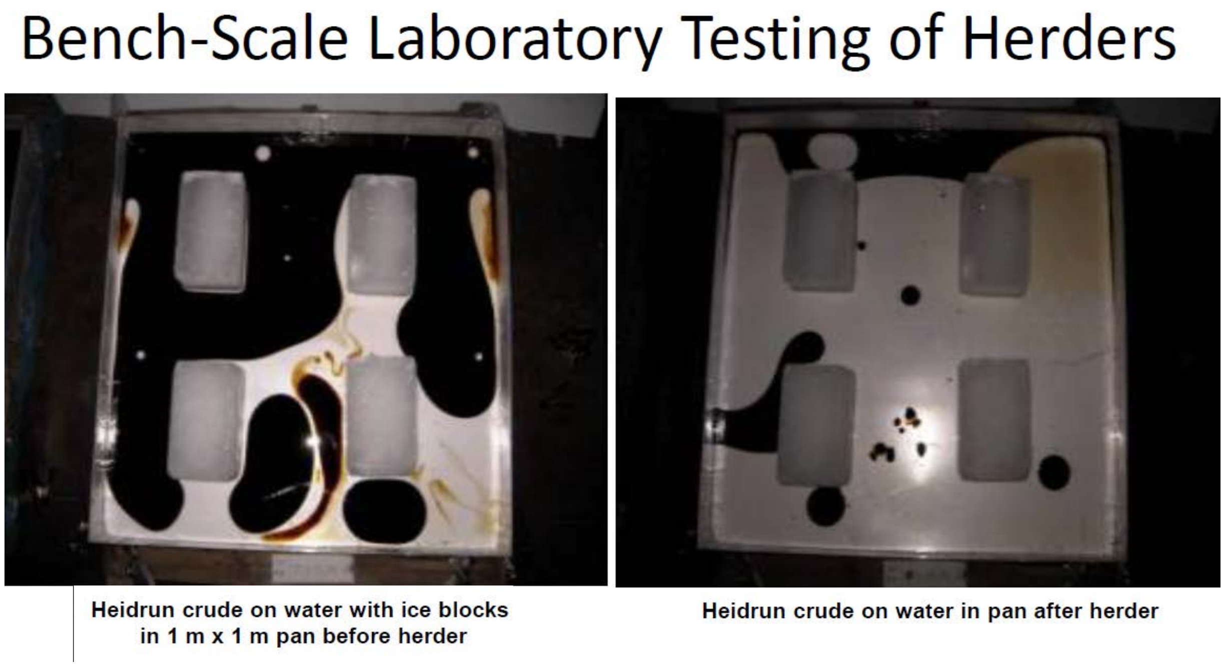

Figure 8. Small-scale lab testing of herding agents.

Further small-scale (1 m^2) experiments were carried out in 2005 [20] to explore the relative effectiveness of three oil hydrocarbon-based herding agents in simulated ice conditions; followed by larger-scale (10 m^2) quiescent pan experiments to explore scaling effects (Figure 9); small-scale (2 to 6 m^2) wind/wave tank tests to investigate wind and wave effects on herding efficiency; and finally, small ignition and burn tests. These tests identified ThickSlick 6535 as an effective herding agent on cold water and in ice conditions, raising the readiness of herding technology to TRL 4.

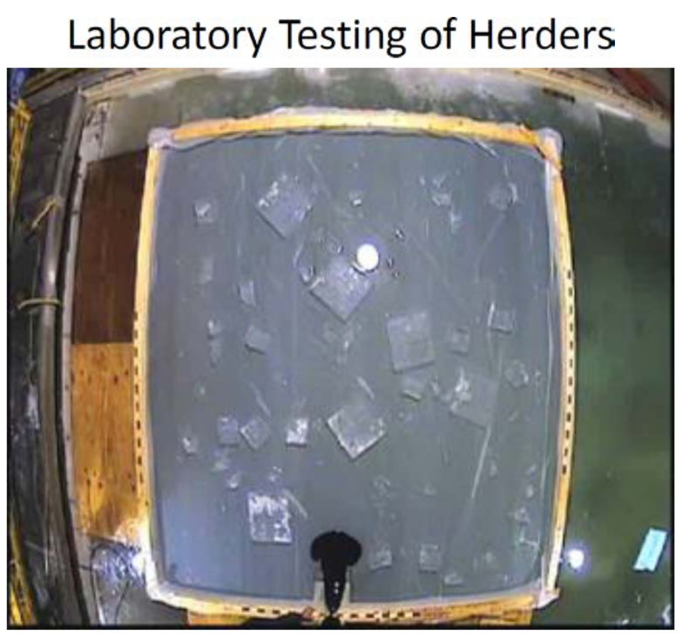

Figure 9. Mid-scale lab testing

The next phase of research and development involved larger-scale tests under controlled conditions, with experiments performed at the scale of 100 m^2 in a simulated environment at the indoor Ice Engineering Research Facility Test Basin at the US Army Cold Regions Research and Engineering Laboratory (CRREL) in November 2005 (Figure 10) [21]. In 2006, near full-scale experiments were undertaken with the ThickSlick 6535 herder at the scale of 1000 m^2 at Ohmsett in artificial pack ice (SL Ross 2007). A series of 20 burn experiments were carried out in 2007 with the ThickSlick 6535 herder at the scale of 30 m^2 in a specially prepared test basin containing broken sea ice in November 2006 at the Fire Training Grounds in Prudhoe Bay, AK with fresh crude oil (Figure 10) [22]. Together these three tests in relevant environments advanced herder technology through TRL 5 to TRL 6.

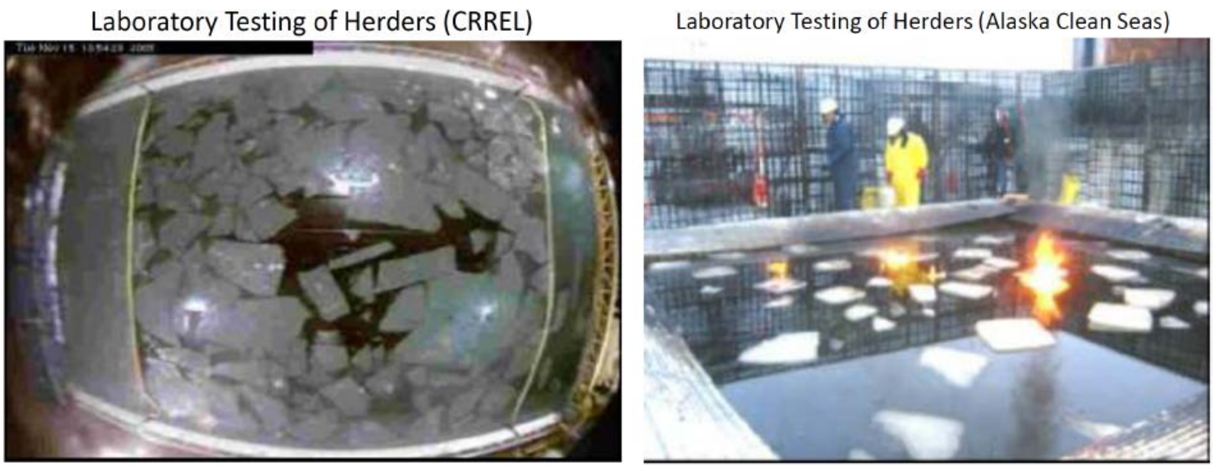

Figure 10. Mid-scale lab testing at CRREL on the left and Alaska Clean Sea on the right photograph.

Full scale field tests in pack ice in the Barents Sea were done in 2008 (Figure 11), advancing herders through TRL 7 [23]. One experiment involved the release of 630 L of fresh Heidrun crude in a large lead. The free-drifting oil was allowed to spread for 15 minutes until it was far too thin to ignite (0.4 mm), and then ThickSlick 6535 herder was applied around the slick periphery. The slick contracted and thickened for approximately 10 minutes at which time the upwind end was ignited using a gelled gasoline igniter. A 9-minute long burn consumed an estimated 90% of the oil.

Figure 11. Full-scale field test of herding agents in drift ice in the Barents Sea

Studies on better herding surfactants were completed between 2008 and 2010 [24,25] identifying OP-40, a silicone-based herder, as being more efficient at herding oil. Following their successful use in controlled settings there was a desire to test operational aspects of herder use in a less-controlled offshore environment and to examine the requirements for their approval in marine spill response. These studies provided data to validate performance claims, and to establish performance and operability limitations, key accomplishments to achieve in TRL 8.

A project was initiated to gain approval for a series of tests in the Caspian Sea however it soon became apparent that approval would be difficult. Instead, a shallow test pond constructed in Fairbanks, Alaska was used for five experimental releases in April 2015 (Figure 12 and Figure 13). An application system, consisting of a pump, controls and reservoir were designed to be placed inside an appropriate helicopter. It incorporated a reel-able hose that was used to lower the application nozzle to the correct height above the water for herder application. Dry land, static trials were conducted followed by helicopter flight trials. In these tests, the fully integrated aerial system was demonstrated, used by the intended operator (a pilot), and safety procedures were established to support achievement of TRL 8.

Figure 12. Ignition attempt during full-scale test in Fairbanks

Figure 13. Full-scale in-situ burn in Fairbanks tests

Desmi-AFTI worked in conjunction with SL Ross Environmental Research to get regulatory approval to use herders in North American waters. The proscribed test data from an accredited laboratory in Louisiana on three candidate herding agents (also called surface collecting agents) was submitted to the U.S. EPA for approval to list them on the National Contingency Plan (NCP) Product Schedule. Two herders have been placed on the list and are now commercially available. These two can be used, with the

Federal On-Scene Coordinators (FOSCs) concurrence, for spill response operations in U.S. waters. Samples of all three herders have been sent to Environment Canada, along with all the EPA test data, for their consideration. Quantities (200 L) of the two herders listed on the NCP Product Schedule have been produced and are stockpiled at Desmi-AFTI in Buffalo, NY. At this time no herders have been approved for use in other Arctic waters. The culmination of the research program on herders has brought this technology to TRL 8. Table 10 summarizes the progression of herders through the range of TRLs.

Table 10: Summary of TRL Progression for Herders in Conjunction with In-Situ Burning

Milestone	Date	TRL
R&D on herders for open-water application	1970s	2
Small-scale lab testing	2003	3
Small-scale lab testing to refine effectiveness parameters	2005	4
Small-scale wind/wave tests, burn test	2005	4
Mid-scale lab testing (CRREL)	2005	5
Near full-scale testing (Ohmsett)	2006	6
Mid-scale burn testing (Alaska)	2006	6
Full-scale field tests (Barents Sea)	2008	7
Small-scale lab testing to refine optimum herder formulations	2008 to 2010	8
Full-scale field tests of operational aspects (Fairbanks) Acquisition of regulatory approval	2015	8

6. SPILL ENVIRONMENTS AND RELEVANT TEST ENVIRONMENTS

Unlike other communities, an oil spill response can have many different environments for a single spill. Offshore environments can be classified based on two considerations, how far the oil is from the shore and how deep the spill response is from the surface of the water. An example of the spill environments experienced during the Deepwater Horizon event is shown Figure 14. For reference the pelagic zones are shown as on the right hand side of the image. In addition to the distance from shore and depth, the ice conditions are also important for cleaning up oil spills. NOAA's Observers Guide to Sea Ice provides a very good description and set of visual images and pictures to describe the sea ice coverage and type. Figure 15 shows a schematic used to classify sea ice coverage and Figure 16 shows an example of 5 to 6 tenths "open drift" ice.

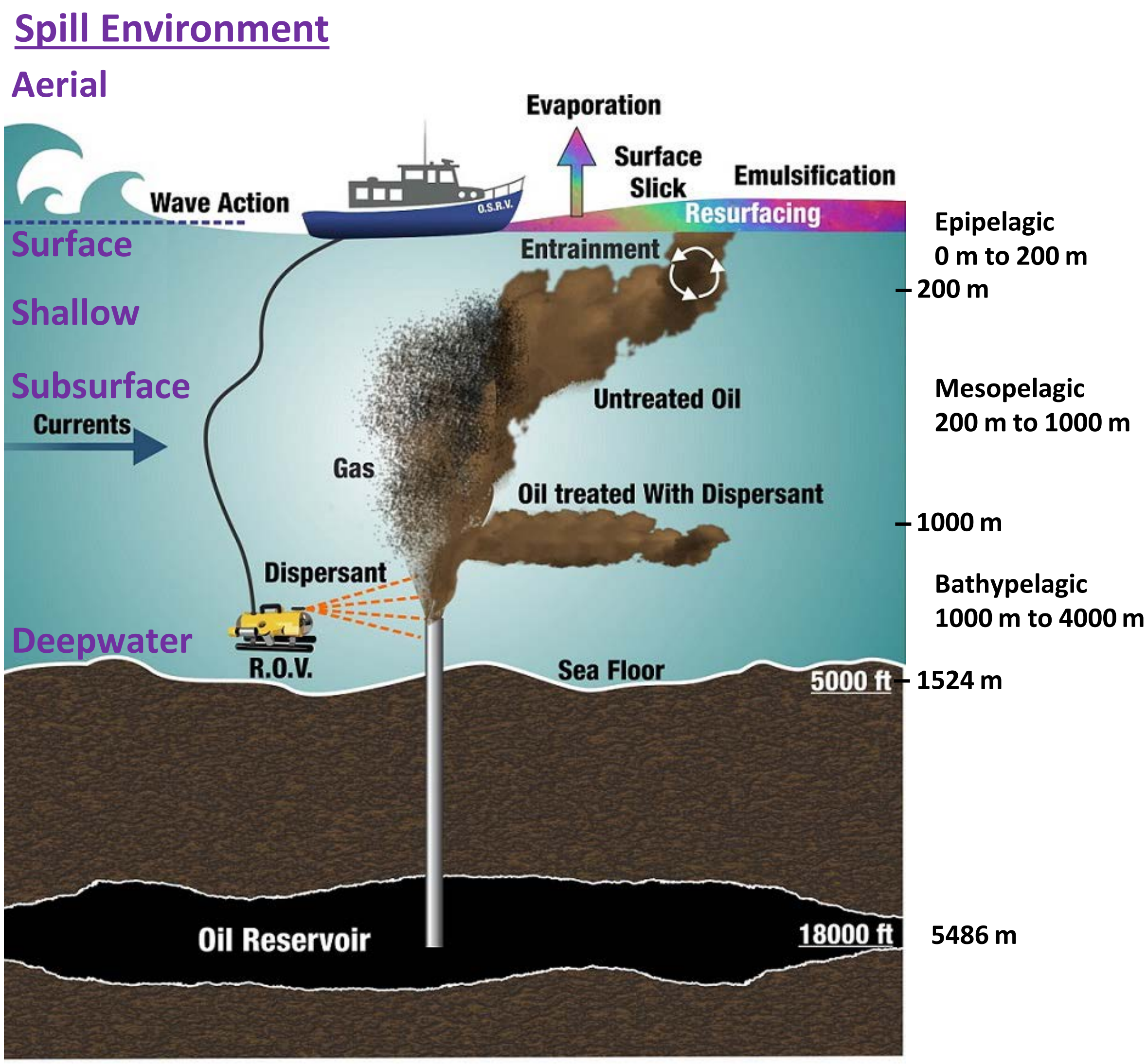

Figure 14. Operational spill environments, cross-referenced to oceanic depth zones.

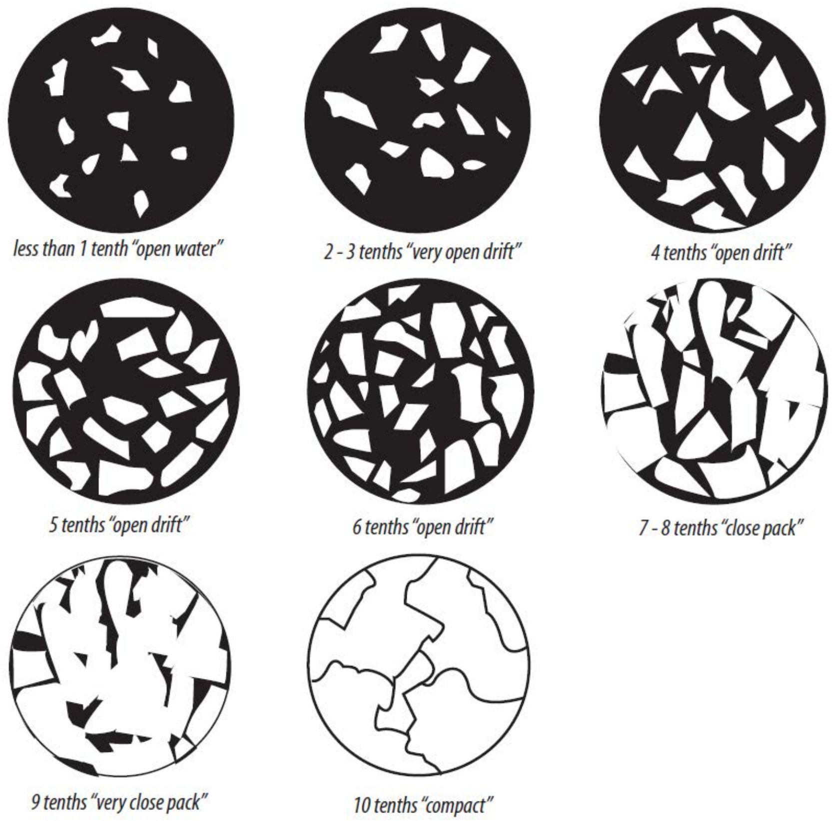

Figure 15. Diagrams of ice coverage.

5 - 6 tenths "open drift"

Figure 16. Photograph of 5 – 6 tenths coverage of an open drift ice field.

There are many facilities that can perform oil spill research and technology development and the number is steadily growing. We have compiled a list of some of the facilities that are commonly used. This list is not comprehensive but provides an example of various spill environments and some of the corresponding relevant test environments that the response community can use to test and develop their ideas and technologies. In general, there are many facilities that can replicate the near shore environments where the water is less than 10 meters deep with waves as high as 1 meter. However, there are very few facilities that can replicate the pressure and temperatures expected at the depths seen in the Deepwater Horizon blowout. There are numerous facilities that can create various ice conditions, butfew that can be used to test and develop aerial deployed technologies. A key gap is a facility that can simultaneously create the depths, currents, and openness expected in the open ocean.

Each of these spill environments have unique physical characteristics and thus require technologies with unique specifications. As an example, technologies designed to spray dispersants on the surface of the water from a boat or from an airplane could not be directly utilized to apply dispersants at the wellhead in the deepwater environment in the Macando incident. During the spill, the response team rapidly advanced the sub-sea dispersant application tools through several TRLs for the new intended deepwater environment. The team successfully injected dispersant into the plume of a real spill environment at a depth of approximately 1500 meters.

For the environments in Figure 14, there are several facilities that could be used as relevant test environments. Specifically for surface and shallow environments at depths less than 9 meters there are several facilities including Ohmsett, SINTEF, CRREL, SL Ross, VIMS/ARA, SERF, CEDRE, and the Coastal Response Research Center. Some of these facilities are multi-use and can be used for several different scenarios and technologies. For example, SERF and CRREL can study oil in ice environments, and CRREL, WPI, and SL Ross facilities can support ISB studies. Unique to the needs of deepwater blowouts, both SwRI and Penn State have pressure chambers that can mimic deepwater environments. While the facilities cover a wide range of spill environments, there are limited facilities for aerial testing and for deepwater testing. Significantly there are no facilities that can simultaneously mimic a spill in the open ocean in the deepwater. For the remainder of this section we will provide description of some of the facilities mentioned and summarize by matching the spill environments with the relevant test facilities.

While this list of facilities is not conclusive, it serves to provide the reader with a brief overview of the types of facilities that have been used to perform oil spill research. Below, Table 11 shows the spill environments and the test facilities mentioned in this report that have relevant test environments that correspond to the specific spill environments. Based on our current understanding of the test facilities there is a gap in relevant environments to test aerial applications and subsurface applications below approximately 10 meters in depth.

Table 11. Correlation between spill environments/conditions and a sampling of facilities with the relevant test environments

Spill Environment / Condition	Test Facility												
	CRRC	CRREL	CEDRE	JMTF	Ohmsett	Penn State	Poker Flats	SERF	SINTEF	SL Ross	SwRI	VIMS/ARA	WPI
Aerial							✓						
Surface Wave Tank (< 1 m)			✓	✓	✓			✓		✓			
Shallow Subsurface (<10 m)	✓	✓	✓		✓	✓		✓	✓	✓	✓	✓	✓
Mid-depth Subsurface (10 m to 1800 m)						✓					✓		
Deepsea (>1800 m)						✓					✓		
Arctic/Ice		✓			✓		✓	✓	✓	✓			
ISB		✓		✓			✓			✓		✓	✓

CRRC: The Coastal Response Research Center
CRREL: The Cold Regions Research and Engineering Laboratory
CEDRE: The Center of Documentation, Research and Experimental on Accidental Water Pollution
JMTF: The Joint Maritime Test Facility
SERF: The Sea-ice Environmental Research Facility
SwRI: Southwest Research Institute
VIMS/ARA: Virginia Institute of Marine Science/Applied Research Associates
WPI: Worcester Polytechnic Institute

6.1 Coastal Response Research Center and Center for Spills and Environmental Hazards

The Coastal Response Research Center (CRRC) was established as a partnership between the National Oceanic Atmospheric Administration (NOAA), through the Office of Response and Restoration, and the University of New Hampshire (UNH), through the Environmental Research Group in 2004. The Center for Spills and Environmental Hazards (CSE) is a University center that expands the scope of interaction and cooperation with the private sector, other government agencies and universities. The Centers are administered by, and located at, the UNH campus in Durham, NH. Both centers are affiliated with the UNH School of Marine Science and Ocean Engineering. The CRRC has a circular flume with a 2000 L capacity used for spill behavior research with recent studies including the disposition and movement of sunken oils.

6.2 Cold Regions Research and Engineering Laboratory

The Cold Regions Research and Engineering Laboratory (CRREL) solves interdisciplinary, strategically important problems of the U.S. Army Corps of Engineers, Army, Department of Defense, and the Nation by advancing and applying science and engineering to complex environments, materials, and processes in all seasons and climates. CRREL maintains unique expertise related to the Earth's cold regions. CRREL is a national resource ready to focus its unique capabilities to solve specific customer-driven problems and conduct innovative, state-of-the-art research.

CRREL has many unique and specialized research facilities. Located at its Hanover, N.H., complex are 24 low-temperature research cold rooms with a temperature range down to -35 degrees Celsius, the 73,000 square foot Ice Engineering Facility, and the 27,000 square foot Frost Effects Research Facility including a 120 × 30 × 8 ft tank and a 10 × 10 ft preparation tank. The Corps of Engineers' Remote Sensing/Geographic Information Systems Center of Expertise is located at CRREL, along with the Cold Regions Science and Technology Information Analysis Center. CRREL also has special purpose ice test facilities, low temperature materials laboratories, a research permafrost tunnel in Fox, Alaska, a 133-acre permafrost research site near Fairbanks, Alaska, and a project office in Fairbanks.

CRREL has been involved in numerous studies of oil in ice as well as ISB for many years and has many unique facilities suitable for oil spill studies. Figure 17 shows an experiment on chemical herders applied manually in an ice field in one of their cold rooms. Figure 18 shows an ISB in an ice cavity, and Figure 19 shows burning of oil collected in a recovery trench. In the foreground, oil residue in broken ice is visible in the pit from previous burn.

Figure 17. Testing of chemical herding agents at CRREL.

Figure 18. In-situ burning in ice at CRREL.

Figure 19. Burning of oil in a recovery trench in ice at CRREL.

6.3 Center of Documentation, Research and Experimentation on Accidental Water Pollution

The Center of Documentation, Research and Experimental on Accidental Water Pollution (CEDRE) has facilities that allow full scale simulation of real life spills, in an environmentally friendly manner. The facilities cover 3 hectares including a man-made beach and a 90 cm deep water basin. Figure 20 shows their flume tank which is 0.6 m wide and 1.4 m deep. The flume simulates the conditions during the first few hours following a spill. It can sustain wave height of 25 cm at a frequency of 6 seconds, currents of 20 cm/s and winds of 3 m/s in a water volume of 7 m^3 (1850 gallons) at a depth of 90 cm.

Figure 20. The flume at CEDRE.

CEDRE also has an outdoor basin that is 59 m x 35 meters and holds water up to 3 m deep. The basin can accommodate typical boom and skimmer arrangements. The basin shown in Figure 21 is used for containment and recovery exercises as part of practical training courses. An artificial beach and its water body are contained in a basin in the form of a trapezium with a surface area of 6,000 m^2; used for large-scale simulation of pollution on varying shore types for research and training purposes, i.e. spill assessment and clean-up

Figure 21. The outdoor basin at CEDRE.

6.4 JOINT MARITIME TEST FACILITY

The Joint Maritime Test Facility located on Little Sand Island near Mobile, Alabama has a tank measuring 30 m x 9.2 m x 1.5 m. While it has wave generating potential it is not currently operational. The wave generator is designed to create with amplitudes of 24 inches and a frequency of 1-20 seconds. The tank can be filled with salt water from Mobile Bay, and supports full scale ISB studies.

Figure 22. The test tank at JMTF.

Figure 23. the wave paddle in the test tank at JMTF.

6.5 OHMSETT

Ohmsett – The National Oil Spill Response Research & Renewable Energy Test Facility provides independent and objective performance testing of full-scale oil spill response equipment to help improve technologies through research and development. The outdoor saltwater wave/tow tank facility is 203 meters long by 20 meters wide by 3.4 meters deep and contains 2.6 million gallons of salt water. It can provide full-scale oil spill response equipment testing, research, and training in a marine environment with oil under controlled environmental conditions (waves and oil types). The facility shown in Figure 24 is located an hour south of New York City, in Leonardo, New Jersey, and is maintained and operated by the U.S. Department of Interior's Bureau of Safety and Environmental Enforcement (BSEE) through a contract with MAR, (MD) LLC of Rockville, Maryland.

Figure 25 shows the tank in use for subsurface releases of oil, gas and dispersants during BSEE funded work. The main towing bridge can tow test equipment at speeds up to 6.5 knots. The wave generator is capable of simulating regular waves up to one meter in height, as well as a complex wave patterns such as simulated harbor chop, FM Slides with selectable: slue rates, start and stop; as well as Pierson-Moskowitz & JONSWAP spectra parameterized by wind speed and scale. The tank has a movable, wave-damping artificial beach, a centrifuge system to recover and recycle test oil, blending tanks with a water and oil distribution system to produce custom oil/water emulsions for testing as well as a wet chemistry lab. Ohmsett can also handle oil in ice conditions.

Figure 24. The Ohmsett test facility in Leonardo, NJ.

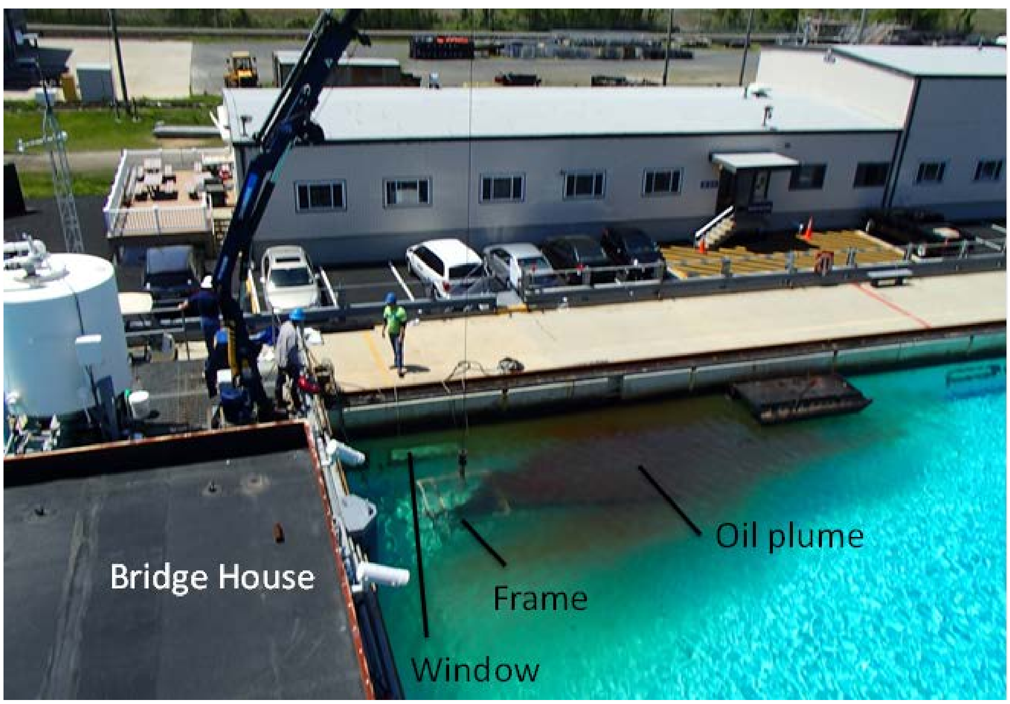

Figure 25. Testing of dispersant application for subsurface releases of oil and gas in the Ohmsett tank.

6.6 Pennsylvania State University Applied Research Laboratory Deep Ocean Test Facility

The Penn State Deep Ocean Test Facility located in Annapolis MD is a unique facility that can achieve pressures up to 12,000 meters in depth in various chambers. Figure 26 shows the large pressure tank measuring 13' x 27' which is capable of achieving pressures up to 9000 m deep with saltwater or fresh water. Similarly Figure 27 shows the vertical high pressure tank measuring 5' x 13' which can achieve pressures as deep as 12,000 meters in freshwater.

Figure 26. A horizontal high pressure chamber at the Deep Ocean Test Facility.

Figure 27. A vertical high pressure chamber at the Deep Ocean Test Facility.

6.7 POKER FLATS RESEARCH RANGE

The Poker Flats Research Range is located North of Fairbanks, Alaska, and has a 10,000 square meter (100 x 100 m) shallow outdoor tank (less than 1 meter depth) which can support aerial applications from helicopters and ISB operations. It has been used for testing chemical herders for use during in-situ burning in ice conditions.

Figure 28. The shallow basin covered in ice at Poker Flats.

Figure 29. Helicopter tests at Poker Flats outdoor test basin.

6.8 SEA-ICE ENVIRONMENTAL RESEARCH FACILITY

The Sea-ice Environmental Research Facility (SERF) is located at the University of Manitoba, Winnipeg, MB and has a large, outdoor, saltwater pond equipped with a suite of state-of-the-art analytical instruments. Researchers can watch and monitor the formation of sea ice under controlled conditions on the water for comparison with what occurs in the high Arctic. The pool measures 20 m long, 10 m wide and 2.5 m deep and is equipped with a movable roof to control snow cover and ice growth, as well as various sensors and instruments to allow real-time monitoring. Currently the facility is not designed to handle oil in the ice tank. However, they are in the process of designing a new facility to specifically study the behavior of oil spills in the sea ice environment as well as possible remediation techniques.

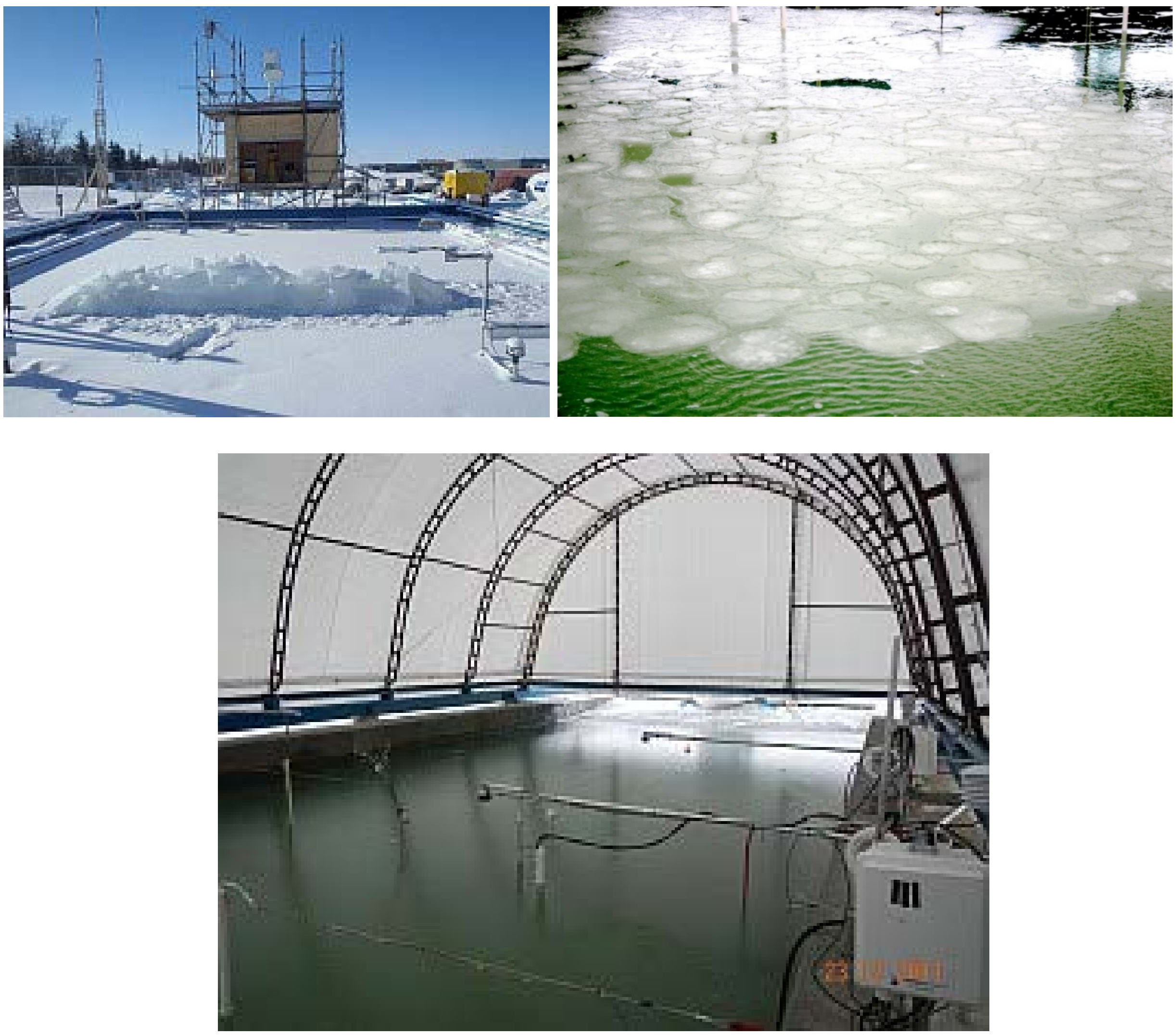

Figure 30. The outdoor saltwater pond in various stages of ice coverage and with the movable roof over the tank.

6.9 SINTEF

SINTEF is located in Trondheim, Norway and has several facilities used for oil spill response research including a large tower basin tank shown in Figure 31 and Figure 32. The tower basin is 6 meters tall and 3 meters in diameter an can handle subsurface releases of oil, gas, and dispersant in salt water. SINTEF has various sensors in house for monitoring the experiments, a flume, and several other smaller tanks for oil spill testing at different scales.

Figure 31. The tower basin at SINTEF.

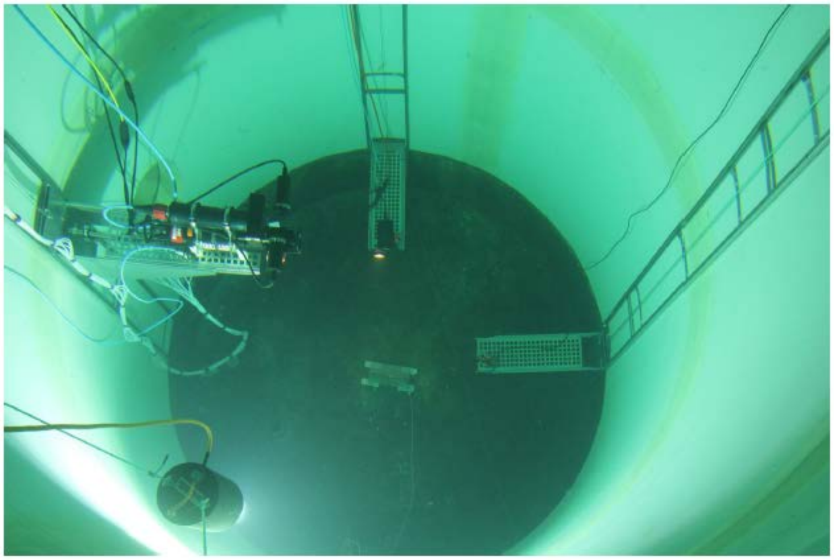

Figure 32. The inside of the tower basin at SINTEF prior to a subsurface release of oil.

6.10 SL ROSS ENVIRONMENTAL RESEARCH LIMITED

The facilities at SL Ross have been used over the years for many types of oil spill response research and technology development including ISB, herder development, and dispersant studies. Figure 33 shows their flume tank, constructed primarily to perform weathering experiments. It consists of a working channel 0.5 meters wide, 1.5 meters deep, with a total center-line length of 8.7 meters. The overall footprint is 2.0 meters wide by 4.8 meters long including a wave generating section. Water temperature is controlled using a chiller and heat transfer coils mounted within the water column. A UV source is used to simulate solar radiation, while a ventilation fan is used to extract vapors. The tank enclosure is covered by clear polycarbonate sheets to provide an air chase above the water surface and block stray UV light. Water currents are created using fans mounted within the air chase or twin thrusters mounted vertically within the water column. A reciprocating wedge may also be used to generate small waves. The flume tank can be used for weathering & dispersant studies.

Figure 33. The flume tank at SL Ross.

Figure 34. The wave tank at SL Ross.

Figure 34 shows the SL Ross wave tank, approximately 12.5 meters long by 1.2 meters wide by 1.3 meters deep, was constructed primarily for conducting fate and behavior testing of oils and dispersants. A computer controlled wave paddle capable of producing sinusoidal, breaking, or random waves in a variety of spectra including Pierson-Moskowitz, JONSWAP, Bretschneider, and others is mounted at one end of the tank. At the opposite end of the tank, a mechanical beach consisting of 12 screened plates has been installed to dissipate the wave energy. Two large viewing windows are installed on opposite sides of the tank, while two smaller windows are installed at the bottom of the tank to allow unimpeded viewing and recording capabilities during experimental runs. Insulated covers to provide an air chase have been constructed along with an insulation system (not shown in photo). Two chiller systems have been installed to cool the tank water and air above the tank to allow the production of ice during arctic simulations and cold weather testing.

6.11 SOUTHWEST RESEARCH INSTITUTE

The Ocean Simulation Lab Southwest Research Institute (SwRI) has unique high pressure testing facilities to conduct testing and performance evaluation services in more than 10,500 square feet of air conditioned laboratory space and 12 ocean simulation test chambers that range in pressures to 30,000 psig and sizes to 90-inch diameter. They have various options for electrical, liquid and gas feed penetrations through the tank that can support component testing, and simulating subsea releases of "live" oil. A full list of their tanks is in Table 12 and pictures of two of their larger tanks are shown in Figure 35.

Table 12. Pressure tank capabilities at SwRI.

Maximum Pressure (psi)	Simulated Ocean Depth (feet)	Maximum I.D. (inches)	Inside Length (inches)	Minimum Temp (°F)	Maximum Temp (°F)	No. of Penetrations
3,300	7,415	48	178	32	200	12
4,000	8,988	90	230	32	100	30
6,000	13,483	50	288	32	100	8
10,000	22,471	6	41	32	500	2
10,000	22,471	30	114	32	200	10
10,000	22,471	9	46	32	600	4
11,000	24,719	8	90	32	600	2
20,000	44,943	10	34	32	600	6
20,000	44,943	12	120	32	400	2
20,000	44,943	15	120	32	100	4
30,000	67,000	16	120	32	500	4

Figure 35. Two high pressure chambers at Southwest Research Institute.

6.12 VIRGINIA INSTITUTE OF MARINE SCIENCE /APPLIED RESEARCH ASSOCIATES

The ARA facilities at The College of William & Mary, Virginia Institute of Marine Science (VIMS) in Gloucester Point, VA have a unique Seawater Research Laboratory (SRL) which allows scientists from VIMS and other institutions to conduct research on living marine and estuarine organisms under controlled conditions as well as facilities of large tanks for oil and dispersant experiments. The SRL facility consists of six primary contained wet lab areas. There are areas designed to accommodate the basic culture requirements of a wide variety of benthic, planktonic, and large nektonic aquatic organisms. The high bay area shown in Figure 36 has a ceiling clearance of 10 meters to accommodate large equipment for testing and developing oil spill response technologies that require large areas. The facility has access to brackish water from the York River Estuary as well as fresh water. The SRL can be used for large scale experiments in tanks as shown in Figure 37 and oil and dispersant experiments as shown in Figure 38. The SRL also has bio safety labs at up to level 3 and has the facilities to perform toxicity studies of oil and dispersants on marine wildlife.

Figure 36. The high bay area at the VIMS Seawater Research Laboratory

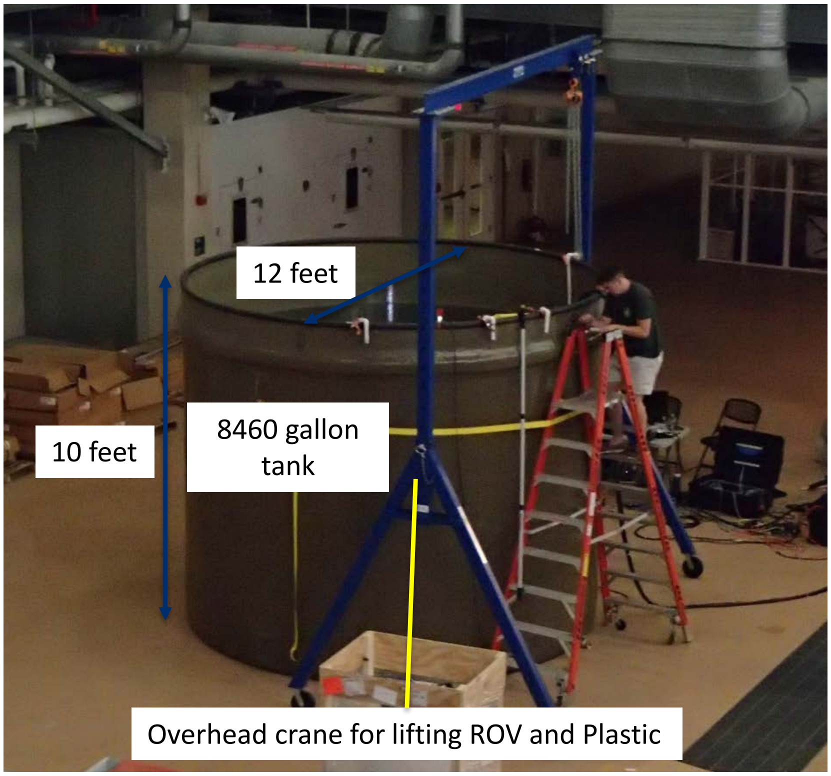

Figure 37. A large tank for oil testing installed at in the VIMS Seawater Research Laboratory.

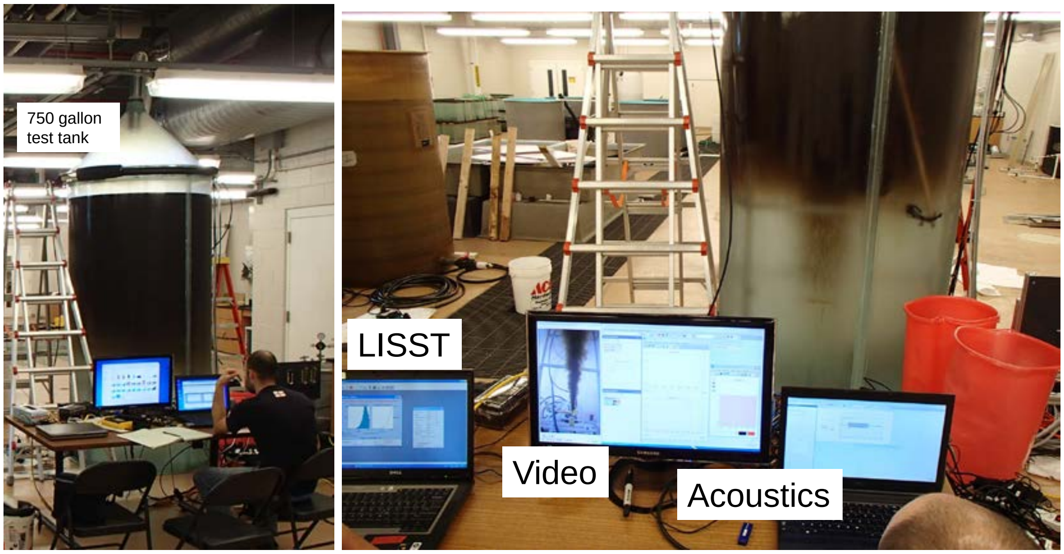

Figure 38. Testing of subsurface releases of oil and gas at the VIMS Seawater Research Laboratory.

6.13 WORCESTER POLYTECHNIC INSTITUTE

Worcester Polytechnic Institute (WPI) has unique fire engineering labs that have been used for ISB studies. The UL Fire Protection Engineering Performance Laboratory shown in Figure 39 consists of a 190-square-meter floor space with a 9.2-meter-high ceiling, enabling experiments on test specimens up to two stories tall. The centerpiece of the laboratory is a 6-megawatt calorimeter, called LODS G2, which features a 6-meter by 6-meter exhaust hood located 6 meters above the lab floor. This space is ideal for testing open burning fires, medium-scale compartment fires, exterior façade fires, and more. It can also be used to replicate certain external exposure fire conditions (e.g., wildland). LODS G2 is capable of collecting smoke from intermediate scale burns and providing a heat release rate history and can support data acquisition through devices such as heat flux gauges and thermocouples.

Figure 39. An in-situ burning experiment at the UL Fire Protection Engineering Performance Laboratory at WPI.

The Honeywell Fire Protection Engineering Fundamentals Laboratory contains a cone calorimeter, two FM Global Fire Propagation Apparatus, and an Intelligent Laser Applications GmbH 75-megawatt fixed optical path length fp50-shift LDA system supported by an automatic traversing system, which can be used to make accurate velocity measurements. The lab also contains a thermogravimetric analysis apparatus, a differential scanning calorimeter, ovens, and hooded bench space. These pieces of apparatus enable researchers to conduct a wide range of small-scale experiments and tests.

Figure 40. Combustion experiments at the WPI combustion laboratory.

WPI also has a combustion lab shown in Figure 40 which occupies 1500 feet of space in Salisbury Laboratories. It houses 1 fume hood and 2 large hoods (4000 cfm), in addition to student offices and a small conference room. Equipment in the lab includes an intelligent Laser Applications GmbH (ILA) 75 mW fixed optical path length fp50-shift LDA system for measuring velocity, an environmental chamber (-30ºC to 40ºC), a Servomex ServoTough Oxy paramagnetic oxygen analyzer capable of measuring oxygen concentration in corrosive environments, and a Servomex Oxy paramagnetic gas analyzer for measuring CO, CO_2 and O_2 vapor.

7. SUMMARY AND CONCLUSIONS

We developed the BSEE TRLs for oil spill response technologies and equipment with input from a broad spectrum of the oil spill response community. They ranged from TRL 1 with basic science exploration for future technology applications to TRL 9 where the technology is deployed for a real spill. We classified several test facilities and correlated them with spill environments. While there are many facilities there is a limited number for aerial testing and for depths greater than 10 meters. There are few facilities with more than 3 test environments and no facility for simultaneous control of depth, current the open space of the deep ocean.

8. RECOMMENDATIONS AND FUTURE WORK

Based on our findings, and numerous discussions, implementation of the TRLs would be simplified if a web based TRL “calculator” was created that utilizes a series of questions to unambiguously and automatically determine a technology’s TRL. Additional granularity for the TRLs similar to the Department of Energy Marine and Hydrokinetic TRLs would be useful for helping the community understand and use the TRLs. It would also be useful to classify and compile the specifications of the various test facilities around the world and match them to various spill environments in more depth. In addition, more specific definitions of the spill environments would help the community understand which technologies to deploy for a given spill and where to focus during technology development. Another useful application of the TRLs would be to categorize the database of projects on the BSEE website to include the TRLs so that people looking for specific technologies at specific TRLs could easily find them.

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APPENDIX. BSEE TRL WORKSHOP ATTENDEES

First Name	Last Name	Organization
Kimberly	Bittler[1]	BSEE
Victoria	Broje[2]	Shell
Stephanie	Brown[1,2]	Naval Sea Systems Command
Per Johan	Brandvik	SINTEF
Suzanne	Chang	BSEE
Erik	DeMicco[1]	ExxonMobil
David	DeVitis[1]	Ohmsett/Mar Inc.
Alan	Guarino[1]	Ohmsett/Mar Inc.
Kurt	Hansen	USCG
Nate	Lamie	CRREL
Glenn	Mahnken	Worcester Polytechnic Institute
Lori	Medley[1]	BSEE
Paul	Panetta[1]	ARA/VIMS
Scott	Pegau	OSRI
Steve	Potter[1]	S. L. Ross
Pete	Reno	Ohmsett/Mar Inc.
Tim	Robertson	Nuka Research
Bill	Schmidt	Ohmsett/Mar Inc.
Phil	Stimac[1]	ARA
Chris	Storey	SwRI
Dave	Sweeten	BP
Don	Toenshoff	MSRC
Keith	Van Dyke	Ohmsett/Mar Inc.
Len	Zabilansky	CRREL

[1] Organizing Committee
[2] Participated via WebEx