300117

2014 INTERNATIONAL OIL SPILL CONFERENCE

ADVANCEMENTS IN UNDERWATER OIL DETECTION AND RECOVERY TECHNIQUES

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ABSTRACT 300117:

The marine salvage and commercial diving industries have increasingly been sought out to prevent oil spills from submerged shipwrecks, and to detect and recover spilled oil below the surface once a subsea spill occurs. In recent years, underwater oil recovery techniques have advanced from predominantly surface-supplied diver installed vacuum or pumping systems in relatively shallow waters to the use of saturation diving systems and remotely operated vehicles at greater depths. Underwater oil detection technologies have advanced permitting the detection of spilled oil in the water column, on the bottom and in the subsurface. For oil trapped within a sunken shipwreck, neutron backscatter technology has been successfully applied to locate oil inside the ship. Additionally, the International Maritime Organization, U.S. Coast Guard and National Oceanic and Atmospheric Administration have published regulations, guidance and studies in the past five years in an effort to improve submerged oil detection and recovery operations. This technical paper will provide an overview of the regulatory framework, basics of underwater oil spill response operations and an analysis of recent technological advances available to detect and recover oil at depth. Multi-beam sonar, real-time mass spectrometry, saturation diving systems, diver-operated recovery systems, and remotely operated vehicle systems will be discussed. Recent case studies will frame the presentation of advances in subsea oil detection and recovery equipment. Finally, conclusions and recommendations will be presented to further advance submerged oil detection and recovery efficiency and effectiveness.

BACKGROUND:

The Oil Pollution Act of 1990 (OPA 90) primarily focused on mechanical on-water recovery as the preferred oil spill cleanup technique (USCG, 1994). Over 20-years after the passage of OPA 90, however, the effectiveness of on-water oil recovery technology remains only at about a 10-25% recovery rate (NRC, 1999). Despite the ineffectiveness of on-water oil recovery methods, historically the first call by the lion’s share of Federal On-Scene Coordinators (FOSC) is for an Oil Spill Response Organization (OSRO) to respond. The majority of OSROs, however, cannot salvage the vessel or prevent the release of additional pollutants.

The national response priorities outlined in the National Contingency Plan (NCP) state that, after the safety of human life, *“stabilizing the situation to preclude the event from worsening is the* *next priority."* The NCP adds: *"All efforts must be focused on saving a vessel that has been involved in a grounding, collision, fire or explosion, so that it does not compound the problem"* (USCG, 1994). While over the past 15 to 20 years, the salvage and commercial diving industries have increasingly been sought out to prevent oil spills from marine casualties or to mitigate the spill below the surface once it occurs, until the publication of Salvage and Marine Firefighting (SMFF) regulations in 2008 for tank vessels and in 2013 for non-tank vessels, there were no specific regulatory timelines for salvage, lightering and diving services (USCG, 2008 and 2013). In regards to submerged oil response operations, these regulations only apply to vessels carrying Groups I to IV oils and, therefore, do not apply to vessels carrying Group V oils. Note, Group V oils with a specific gravity of less than one typically sink in the water column. Additionally, the regulations define subsurface product removal as only applying to vessels that operate in 40 feet or more of water and limit cargo and fuel recovery operations to depths of up to 150-feet (USCG, 2008).

Recognizing the limitations and constraints of historical subsurface and submerged oil recovery operations, in 2012, the International Maritime Organization published *"Operational guidelines on sunken and submerged oil assessment and removal techniques"* and, in 2013, the U.S. Coast Guard published guidance to their FOSCs (IMO, 2012; Hansen, 2014). In 2013, the National Oceanic and Atmospheric Administration (NOAA) also released the "Remediation of Underwater Legacy Environmental Threats (RULET)" project report that found 36 sunken vessels scattered across the U.S. seafloor that could pose an oil pollution threat to the nation's coastal and marine resources. Of those, 17 were recommended for further assessment and potential removal of fuel oil and oil cargo.[1] The NRT, in their evolving *"Abandoned Vessel Authorities and Best Practices Guidance,"* defines these sunken vessels as "submerged legacy wrecks" located entirely beneath the surface and not presenting a hazard to navigation (NRT, 2013). These recent advances in submerged oil policy and technical guidance build on the foundational studies prepared by the National Research Council published in 1999 and Michel et al in 2005.

The U.S. Coast Guard directs their FOSCs and Incident Commanders to use the "best response" model when responding to an oil spill or potential spill. The Coast Guard's Incident Management Handbook defines "best response" as a response organization that will "effectively, efficiently, and safely respond to oil spills, minimizing the consequences of pollution incidents and to protect our national environmental and economic interests" (USCG, 2006). For submerged oil spills, this best response model can be applied to develop basic rules of engagement or tenets for improving future operations.

BASIC TENETS:

The *Tank Barge DBL 152* incident serves as a foundational case study to outline the basic rules or "best response" tenets for responding to potential submerged oil or hazardous substance releases and to better prepare responders for preventing and responding to these complex incidents. In November 2005, in the wake of Hurricane Rita, the *Tank Barge DBL 152,* carrying approximately 122,500 barrels of non-floating Group V oil, struck a submerged offshore platform and progressively sank, capsized, inverted and ultimately lost the majority of its cargo.

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[1] NOAA's Remediation of Underwater Legacy Environmental Threats (RULET) project report can be found at http://sanctuaries.noaa.gov/protect/ppw/

The volume of oil spilled, its density and its low viscosity combined to make this incident, prior to the *Deepwater Horizon*, the largest and one of the most complex submerged oil response operations in U.S. history (Elliott, Lehmann and Richey, 2008).

Every Salvage Response is Time-Critical: The owner and operator of the *T/B DBL 152* did not initially consider the marine casualty a time-critical salvage operation. While an OSRO was called, a commercial salvor did not arrive on-scene until 48-hours after the collision when the barge was already listing greater than 40 degrees. As a result, a contract for salvage services was delayed preventing timely action. In addition to the National Contingency Plan's priority to immediately stabilize the situation, the Navy Salvor's Handbook emphasizes that marine salvage is "time-critical," noting that while environmental conditions may improve or worsen, the condition of a stranded ship steadily deteriorates (U.S. Navy, 2000).

Advances in the U.S. regulatory framework since this incident now require an assessment of a tank vessel's stability within 3 hours, an on-site assessment in 6 to 12 hours, and a salvage plan within 16 to 22 hours based on the distance from shore. Emergency lightering operations should now commence within 18 to 24 hours, with subsurface product removal operations within 72 to 84 hours[2] (USCG, 2008). However, again, since the regulations do not address vessels carrying Group V oils, the SMFF regulations would potentially not apply to the *DBL 152*.

Keep the Oil or Hazardous Substance inside the Vessel: Once the oil or hazardous substance escapes from the vessel, the chances of recovering even half of the volume released are small. In the case of the *T/B DBL 152*, the majority of cargo was ultimately released, initially pooling on the bottom and then quickly spreading over hundreds of acres. Submerged oil assessment efforts proved problematic. Assessment techniques included (1) visual observations with divers, (2) remote visual observations using dragged or stationary sorbent material, (3) side scan sonar and (4) remotely operated vehicles. No method worked particularly well individually, but some improvements could be realized when methods were combined.

During the *DBL 152* response, the Unified Command reviewed fourteen methods for recovering the submerged oil based on timeliness, operational limitations, recovery efficiency, remobilization potential, cost and safety. Non-mechanical recovery operations, such as dispersants, bioremediation and solidification agents, were quickly discounted. The feasible mechanical recovery option selected, a diver directed system, proved inefficient once the oil had escaped the vessel's hull. Only about 3,800 barrels of the 122,500 barrels originally onboard were recovered. Of note, the OSRO identified in the Vessel Response Plan did not provide adequate procedures and strategies for responding to a worst case discharge of non-floating oil. Additionally, the Area Contingency Plan did not provide guidance on how to effectively respond.

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[2] *On-site salvage assessment* means that a salvage professional is on scene, at a safe distance from the vessel or on the vessel, who has the ability to assess the vessel's stability and structural integrity. The data collected during this assessment is used in the salvage software calculations and to determine necessary steps to salve the vessel. *Subsurface product removal* means the safe removal of oil from a vessel that has sunk or is partially submerged underwater. These actions can include pumping or other means to transfer the oil to a storage device. (33 CFR 155.4025).

The *DBL 152* incident highlighted the limitations in the containment of sunken and submerged oils. Ideally, submerged oil containment will both prevent further spreading of the oil and concentrate the oil to facilitate removal operations. As the 2013 IMO guidance notes, *"silt curtains, pneumatic (bubble) barriers, nets and trawls have all been suggested and some tested in incidents but with varied results."* The report further notes, *"All of these systems were constructed ad hoc, without the benefit of engineering guidelines…"* (IMO, 2013). The on-going submerged oil clean-up effort associated with the 2010 Enbridge pipeline rupture in Michigan provides further evidence of the limitations in containing sunken oil, especially in dynamic and riverine environments (USEPA, 2010).

Thus, the FOSC's first actions should be to immediately stabilize the vessel in an effort to keep the oil and hazardous substances confined to the relative safety of the ship's hull. Lightering oil and hazardous substances from a stable vessel has proved successful on numerous occasions and, in lieu of salvaging the vessel intact, should always be considered before opting to recover the oil and hazardous materials below the water's surface. Advances in submerged oil recovery operations since the *DBL 152* incident include the development of manned submersible oil recovery systems and specialized subsea dredging systems. Additionally, advances continue to be made in the arena of subsea oil detection systems.

Marine Pollution Control developed a two-person submarine fitted with an underwater suction nozzle similar to the hand-held system employed by divers on the *DBL 152*, *ATHOS I* and other historical submerged oil recovery efforts.[3] The submersible unit houses a pilot and one operator in a spherical acrylic cabin to provide visibility in all directions. The system is also capable of hovering over the surface to minimize disturbing the oil impacted area. It has a normal air supply of six hours and a reserve supply of an additional 72 hours. The system is capable of recovering oil at depths of up to 200 feet with an underwater suction nozzle connected to a hydraulic submersible pump capable of pumping 2,400 gallons per minute.

The American Pollution Control Corporation (AMPOL) developed the "Oil Stop Bottom Oil Recovery System" (OSBORS) submerged oil recovery system, developed in coordination with Coast Guard Research and Development, a remote controlled track-driven dredging vehicle designed to remove oil that has settled on the bottom. T&T Marine Salvage also developed a shallow-water dredging system for near shore and inland submerged oil recovery operations. These systems dredge the oil and discharge the pollutants into top-side support equipment for separating recovered oil and in-situ treating of water and solids.

One of the challenges when dealing with Class V oils underwater is the varying nature of the product as it relates to temperature. In the case of the DBL 152, the product could be pumped along with the surrounding water and sediments through centrifugal pumps. This would have been impractical or impossible in the case of the *Kuroshima* that spilled approximately

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[3] On November 26, 2004, the *Athos I*, a 750-foot tanker, hit a submerged object in the Delaware River near Philadelphia, spilling about 265,000 gallons of crude oil. During the assessment phase, an approximately 60-foot trench of pooled oil was found near the location where the vessel hit a submerged object. The recovery of this submerged oil was time critical as the Salem Nuclear Power Plant downstream was reluctant to continue operations until the plant could be assured that a significant volume of oil would not enter their water intakes and potentially damage critical infrastructure.

39,000 gallons of heavy fuel oil near Dutch Harbor, Alaska, in 1997.[4] In this case, the specific gravity of the product exceeded one after evaporation and sediment accumulation. Once the oil entered the fresh water of Summer Bay Lake, it sank to the substrate. In the colder winter water, it congealed into patties that were mechanically picked up by divers. This process likely took more time than pumping or dredging, but had benefits relative to the minimal amount of waste produced. There was no waste water or sediments to be disposed as a result of the removal process.

In addition to the issues outlined with submerged oil containment during the *DBL 152* submerged oil response, remote sensing also proved problematic since the instrumentation used, including side-scan sonar and bottom profilers, required a time delay to interpret data. As a result, the submerged oil had often moved by the time the imagery had been interpreted, results reported and equipment mobilized to the oil recovery site. As part of the subsurface effort to locate oil in the wake of the *Deepwater Horizon* event, T&T Marine Salvage in association with Braveheart Shipping developed a multi-beam echosounder system to detect oil in the water column and on the sea floor. In contrast to the systems used during the *DBL 152* response, data and imagery is now interpreted in real-time by onboard technicians facilitating the immediate direction of tactical assets to recover submerged oil.

Finally, trajectory analysis, real-time tracking of oil and chemical spills and forecasting are critical services during oil spill response operations (NOAA, 2007). However, during the *DBL 152* incident, and as most recently highlighted during the *Deepwater Horizon* response, submerged oil trajectory analysis, tracking and forecasting capabilities are limited. However, some recent progress has been made. For example, in February 2014, the U.S. Geological Survey announced the development of a computer model to “track and predict where oil will go after a spill” (USGS, 2014).

Pay Now or Pay More Later: Submerged oil recovery operations are expensive. During the *T/B DBL 152* response, the vessel’s Certificate of Financial Responsibility (COFR) limit of liability of $11M was exceeded in less than 30 days. While immediately contracting an experienced SMFF service provider upfront may seem like an onerous expense in the short term, the cost pales in comparison to the cost of assessing and recovering oil or a hazardous substance once it has been released into the environment. FOSCs should not be reluctant to immediately contract a salvor and commercial diving firm with experience in underwater oil and hazardous substance recovery techniques. A time-critical vessel casualty with catastrophic potential is not the time to consider using an unproven OSRO. According to Captain Anthony Lloyd, previous Coast Guard Chair of the National Response Team, and Captain Dave Westerholm, Director of the National Oceanic and Atmospheric Administration’s Office of Response and Restoration, *“the technological complexities of attempting lengthy, industrial style work underwater will*

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[4] The Japanese freighter *M/V Kuroshima*, had been anchored outside Summer Bay near Dutch Harbor, Alaska for over three weeks waiting to take on cargo when a powerful storm hit on November 26, 1997. Northerly winds built to 40 to 50 knots with gusts up to 90 knots and seas of 28 to 30 feet. After dragging both anchors, the captain decided to weigh anchor and move the ship. Residents reported seeing the vessel pitching severely in the water on the morning of November 26: *"...from the front beach in Unalaska, we could see her stern rise so sharply as to expose her props and rudder."* (The Dutch Harbor Fisherman, December 18, 1997). The vessel broke anchor and ran aground near Second Priest Rock on the afternoon of November 26, 1997.

require a vastly different collection of experts, equipment, and operational plans than those commonly used for oil spill response" (Westerholm and Lloyd, 2008). In sum, a ship owner can pay upfront and get results or pay more later conducting prolonged assessments, often inefficient recovery operations and long-term monitoring studies.

Focus on Safety: The National Contingency Plan mandates *"the safety of life must be given the top priority during every response action"* (USCG, 1994). Salvage and commercial diving operations pose unique operational risks and safety challenges. The FOSC should ensure the primary Safety Officer and field safety officer assistants are experienced in salvage and diving operations. An experienced offshore inspector, trained in commercial diving operations, is a good choice for an on-scene safety officer. In the case of the bunker removal of the *SS Princess Kathleen*[5] in Juneau, Alaska, the diving involved complex penetration and decompression procedures. The FOSC brought in a diving specialist from the USCG Dive Locker in San Diego, California, to oversee all diving operations. Prior to commencing operations in the US, the commercial diving operation should be inspected in accordance with applicable Coast Guard (46 CFR 197) and Occupational Safety and Health Administration (OSHA; 29 CFR 1910.401-441) regulations. Additionally, when diving in contaminated waters or in an area where there is a substantial threat of discharge of oil or hazardous materials, commercial divers must meet the training and operational requirements of the Hazardous Waste Operations and Emergency Response (HAZWOPER) standards of 29 CFR 1910.120 (OSHA, 1999). Diving in contaminated water requires equipment that protects divers from pollutants. As a rule, if the pollutant is unknown, diving operations should not be permitted (Barsky, 1999). Additionally, SCUBA diving is not appropriate where there is a risk of oil or toxic chemical ingestion (NOAA, 1991). For contaminated water diving, the National Research Council (NRC), U.S. Environmental Protection Agency (USEPA), NOAA and Association of Diving Contractors International (ADCI) have published guidance and protocols.

Stakeholder and Public Outreach: To meet the "best response" criteria, in addition to ensuring the safety of the pubic and responders, minimizing environmental damage and conducting the most cost effective response that reduces impacts to the maritime transportation system, the FOSC must proactively include all interested stakeholders in the decision making process and effectively manage public expectations. In regards to submerged oil recovery operations, the inclusion of both state and federal natural resource trustees will prove vital, particularly when developing clean-up termination endpoints. Communicating the complexities of salvage and subsurface recovery operations in the media poses unique challenges as the environmental impact is often not visible to the reporter. The Unified Command should consider posting representative underwater video clips on-line and contracting a graphic artist to provide a cogent illustration of the salvage or subsurface recovery technique. The International Tanker

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[5] The *SS Princess Kathleen* ran aground on Pt Lena just outside Juneau, Alaska, on September 7, 1952, and then sank just off the point with an unknown quantity of fuel oil in her tanks. From a time shortly after her sinking, the ship had been leaking fuel oil into the surrounding waters until 2010 when the USCG hired Global Diving and Salvage to remove the bunkers from the wreck. Over 130,000 gallons of fuel were removed.

Owner Pollution Federation (ITOPF) noted "conflicts between public expectations and technical limitations," and gaps in expectations and operational possibilities, should be clearly articulated throughout the response (Parker and Moller, 2008). During the 2013 *General Zalinski* submerged oil removal project off Western Canada, for example, coordination with local stakeholders and First Nation representatives was specifically required in the project management plan.

With the basic tenets of submerged oil laying the foundation for initial and strategic operations, lessons learned from previous operations can help formulate tactical operational objectives. The physical properties of the oil, volume spilled, distribution of the pollutant and subsea environmental characteristics will drive detection and recovery decisions. A significant physical constraint will also be the depth at which the oil must be recovered. As such, the following sections divide potential operations and select case studies into operational options, ranging from surface-supplied diving operations to saturation diving systems to remotely operated vehicles.

SURFACE SUPPLIED DIVING OPERATIONS:

Surface-supplied air diving operations are limited by U.S. regulation to a depth of 190 feet seawater (fsw), with the exception of brief excursions to 220 fsw limited to 30 minutes. Mixed-gas breathing mixtures and diving bells must be used for dives deeper than 220 fsw. The NRC's report on spills of non-floating oils recommends operational limitations for diving in contaminated waters to depths of 65 fsw, a minimum visibility of 1.5 to 3 feet, and low water currents (NRC, 1999). However, existing OSHA and USCG regulations allow commercial divers to work in depths in excess of 220 fsw, zero visibility and heavy currents. Additionally, ADCI, USEPA and NOAA do not restrict commercial diving operations to depths that are more stringent than the regulatory depth limitations discussed earlier, nor do they mandate visibility and current-speed standards.

A review of historical submerged oil recovery case studies shows that commercial divers have safely, successfully and routinely completed operations in conditions that exceed the NRC's proposed operational limitations. For example, during the *T/B Apex 3512* oil recovery from the bottom of the lower Mississippi in 1995, divers worked in depths that exceeded 65 fsw, "zero visibility and a strong downriver current" (Weems et al., 1997). Divers encountered similar conditions during the winter of 1995 submerged coal tar recovery in the Detroit River (Heiland et al, 1997).

Based on USEPA studies, diving equipment problems in contaminated water are caused primarily by petroleum products (Traver, 1986). Hazardous substance response operations can create more acute safety risks than oil recovery operations. For example, during the 2003 response to the overturned sulfuric acid barge *NMS-1477* in Texas City, Texas, commercial divers were prevented from initially entering the water due to an extremely low pH level in the water column (Flesner, 2004). In June 2008, during the response to the tragic sinking of the passenger ferry *M/V Princess of the Stars* off the coast of San Fernando in the Philippines, several containers of toxic pesticides were discovered, including 10 tons of endosulfan. Upon discovering the toxic cargo, the Philippines Coast Guard required all divers that had been diving on the wreck to be placed on a medical monitoring program. The salvor, Titan Maritime, contracted Global Diving & Salvage to recover the containers of pesticides. To protect the divers, diving equipment was tested for compatibility with the hazardous substances prior to conducting operations. Additionally, two types of divers dress were selected for this contaminated water operation. For exterior work around the vessel, from 30 to 100 fsw, the divers wore Viking HD dry suits fully mated with a pressure demand helmet fitted with a quadruple exhaust system. For interior work and handling the chemicals, the divers wore Viking HDS, Trelleborg's Hazmat Diving Suit, dry suits fully mated to a positive pressure helmet. Upon completion of every dive, the divers completed a four-step decontamination process, including immersion in two neutralization tanks.

One of the challenges of deeper surface-supplied diving used for hazardous substance response is the need to incorporate decontamination procedures along with decompression procedures which need to follow a close timeline for the diver to enter a hyperbaric chamber after reaching the water's surface. At certain depths, various breathing mixtures can be used to reduce or eliminate the need for surface decompression.

In the past 20-years, surface-supplied divers have been called upon to recover submerged oil spills on numerous occasions, most notably following the 1993 *Tank Barge Ocean 255* and *Tank Barge Bouchard B-155* collision with the freighter *Balsa 37* near the entrance of Tampa Bay, Florida; the 1994 *T/B Morris J. Berman* spill of low API gravity oil off San Juan, Puerto Rico; and the *Kuroshima* and *T/B DBL 152* case studies discussed earlier (Ross, 1994). The 1995 *T/B Apex 3512* response, discussed earlier, pushed the envelope for diver submerged oil recovery, where divers recovered over 500 barrels of Group V oil in zero visibility and heavy river current. The recovery of about 500 barrels of heavy fuel oil at 110-fsw from the *SS Union Faith* in 1999 showed that surface-supplied divers can not only recover submerged oil in extreme conditions, but also locate and tap into the hull to pump fuel tanks from depth in harsh environments.[6]

Today, the installation of hot tap systems or plumbing into existing fuel systems on submerged vessels in relatively shallow waters is a standard marine salvage industry practice, regardless of the environmental conditions, with the requirement specifically codified in waters up to 150-feet in the US SMFF regulations.

SATURATION DIVING SYSTEMS:

Saturation diving is a technique developed in the 1950s by the U.S. Navy that permits divers to work in the deep ocean environment for weeks at a time without having to undergo time-consuming decompression procedures after every dive to dissolve gases that accumulate in the diver's tissue and blood (Navatil, 2002). Once a diver's blood and tissue become fully saturated with the inert breathing gases, typically helium, the decompression time required to remove the gases at the end of exposure does not increase with additional time spent at depth. The time required for total saturation to occur varies (typically between 24 and 36 hours),

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[6] On April 6, 1969, the 503-foot Taiwanese freighter *SS Union Faith* sank in the Mississippi River at New Orleans, Louisiana, after an explosive collision with a tank barge carrying 9,000 barrels of crude oil. Due to recurrent oil releases near the New Orleans waterfront, in 1999, the U.S. Coast Guard contracted Bisso Marine to locate the wreck and recover any accessible oil.

however, depending on the composition of the breathing gases, the ultimate depth of exposure, and the speed at which that depth is attained. Final decompression time also changes as a function of the type of breathing gas and the depth: the greater the depth, the longer the decompression time (Miller and Koblick, 1995). Decompression typically takes between 20 hours and 10 days depending on the parameters of the dive. Divers operating in the saturation diving mode live in a hyperbaric habitat on a barge or dive support vessel (DSV), descend to the bottom in a pressurized diving bell to work, and are then transported back up to their support vessel and reconnected to a habitat pressurized to the diver's work depth.

Case Study - *SS JACOB LUCKENBACH:*

On July 14, 1953, the *SS Jacob Luckenbach*, an ocean freight vessel built in 1944, collided with the *SS Hawaiian Pilot* and sank off the coast of California, 17 miles southwest of the Golden Gate Bridge. Nearly 50-years later in 2002, after years of responding to "mystery spills" from the sunken freight vessel, the U.S. Coast Guard contracted Titan Maritime to recover the accessible oil from the wreck in over 175 fsw. To work safely at depth, Titan subcontracted Global Diving and Salvage to provide a saturation diving system and divers with ROV support to install a viscous oil pumping system to the ship's hull (Fairbanks, 2002).

To recover oil from the ship, Titan Maritime fabricated a submersible hydraulic viscous oil pumping system that included a water injection annulus intake and output to facilitate viscous oil transport at depth with a DESMI 250 pump. Annular water injection is a proven method to reduce friction losses by applying a layer of "lubricating" water between the oil flow and inner sides of the transfer hose. In addition to requiring water injection to facilitate oil transport, a steam injection lance and heat exchangers were fabricated to heat the oil and lower its viscosity. Saturation diving crews successfully ran four separate two-man saturation runs, with an average duration of 28 days, to survey the hull and install the viscous oil pumping system. The salvage team ultimately recovered 85,000 gallons of heavy bunker oil from the wreck. Of note, in January of 2003, the Spanish government contracted Titan Maritime to use a similar system to remove over 264,000 gallons of oil from the bunker barge *Spabunker 4,* resting 165 to 195 fsw below the surface in Algeciras Bay, Spain (Guidotti, 2004).

REMOTELY OPERATED VEHICLES:

Until recently, lengthy underwater oil recovery operations at greater depths typically required saturation diving systems and their associated diving support vessels. SMIT Salvage in co-operation with its Norwegian partner Frank Mohn developed the Pollution Recovery (PolRec) system, also referred to as the Remote Offloading System (ROLS), for oil recovery at depths beyond the limitations of divers (Martin, 2004).

Remotely operated underwater vehicles (ROV), defined as unoccupied, highly maneuverable underwater robots operated by a person aboard a surface vessel, support the PolRec system. The ROVs are linked to the ship by a group of cables that carry electric and hydraulic signals back and forth between the operator and the vehicle.

The PolRec system is a diverless hot tap and submersible hydraulic pump capable of the remote recovery of oil and hazardous substances. It is launched and vertically positioned from the support vessel with a crane. Horizontal movement is controlled with two on-board thrusters and the system is powered from the surface via hydraulic pressure hoses. Each tank requires two penetrations and the installation of base-plates at each of these two hull entries. The lower base plate is equipped with a non-return valve to permit water intrusion and balance tank pressure as oil is pumped from the upper base plate penetration. The upper base plate is equipped with a gate valve to seal the tank once pumping operations are complete. An onboard FRAMO TK-150 pump unit mills the hull penetration. By changing revolutions, the TK-150 pump also serves as the submersible hydraulic pump to transport oil to the surface. Seals around the milling hole and four bolt locations prevent oil from leaking to the surface.

In 1998, the PolRec System proved successful during the recovery of oil from two sunken tankers, *T/V Yu-ll 1* and *T/V O-Sung 3,* off the Korean Coast. In 2001, the system was used to recover chemical cargo and high-viscosity bunker oil from the double-bottomed chemical carrier *Ievoli Sun* in the English Channel off the Island of Alderney (SMIT, 2001). Of significance, this was the first time that cargo was recovered from a double bottom vessel at depth. In 2004, the PolRec system was used for the first time in U.S. waters in an attempt to recover oil from the *T/V Bow Mariner.*[7]

Frank Mohn AS has since developed the ROLS X.0 system. This advanced version of the PolRec system has its own thruster and track system that eliminates the need for the system to be hung from a wire, or an ROV to assist in placement. This system was used to extract oil for the Norwegian Coastal Authority from several WWII vintage wrecks off the coast of Norway between 2011 and 2013.

Response operations beyond the capabilities of traditional working class remotely operated vehicles require more advanced technology. For example, during the *T/V PRESTIGE* response operation nearly 13,000 tons of heavy oil was removed at a depth of over 11,000 fsw. During this operation, submersibles were initially used to assess the wreck. Ultimately, Sonsub upgraded multiple Innovator ROVs for continuous operations in over 11,000 fsw (Fontolan and Galletti, 2005).

In the aftermath of the *Deepwater Horizon* event, the Coast Guard Research and Development Center, in support of the Interagency Coordinating Committee for Oil Pollution Research (ICCOPR), hosted a series of symposiums on oil spill response and recovery (USCG, 2011). The symposiums analyzed the various remotely operated and autonomous vehicles used during the historic response to characterize the subsea plume and submerged oil contamination, including real-time mass spectrometry systems, multi-bean sonar, acoustic profiling systems and fluorescence, among other systems. The final report notes, for the deepwater oil well blow-out release scenario, *"which can result in a submerged oil plume 1,000's of feet below the surface as well as oil on the deep sea bottom, response techniques are essentially non-existent at this time."*

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[7] On February 28, 2004, the *T/V Bow Mariner*, a Singapore-flagged chemical tanker, left Linden, New Jersey, for Texas City, Texas, carrying a partial cargo of 3.2 million gallons of ethanol when it exploded and sank 50-miles off the coast of Virginia in approximately 265 fsw. The oil on board included 192,900 gallons of intermediate fuel oil and 48,000 gallons of marine diesel oil. Due to the continuous outflow of oil from the vessel after sinking, the Unified Command, composed of the U.S. Coast Guard, the State of Virginia and the vessel owner, contracted SMIT Salvage to recover all accessible oil using the remotely operated PolRec system.

These findings reiterate the basic tenets of submerged oil response; every response is time critical and all efforts must be focused on preventing or minimizing the release of oil into the environment.

Case Study – *MONTEBELLO:*

Since the *Luckenbach* project, a neutron backscatter remote sensor, deployed from a working-class ROV, has been used to assess the residual oil in a submerged wreck. In 2011, the S.S. MONTEBELLO, a tank ship that sank off the U.S. West Coast in 1941 at depths up to 900 feet, was assessed for residual oil cargo and fuel. The results of a Neutron Backscatter System were accepted by the FOSC after representative sampling.

The neutron backscatter survey is performed by using a source of high energy, or “fast” neutrons, and a detector that is sensitive to low energy, or “slow” neutrons. The neutron source is held against the side of the vessel under inspection and moved up and down over the surface. Fast neutrons from the source will penetrate the walls of the ship and interact with the medium inside. If the medium is hydrogenous, such as seawater or oil, the neutrons will be slowed by collisions with the hydrogen nuclei. These slow neutrons reflected back out of the ship’s hull will be detected. The detector response is a function of the hydrogen concentration or “hydrogen richness” of the material adjacent to the detector. In general, the higher the concentration of hydrogen nuclei, the greater the magnitude of detector response output. In sum, oil would be expected to produce a higher detector response than water.

As a part of the assessment, a calibration tank designed and fabricated specifically for the ship in question, based on the known and measured hull thicknesses, is utilized on the seafloor next to the wreck to calibrate the readings with ambient conditions and to demonstrate the system’s efficacy to decision makers.

CONCLUSION AND RECOMMENDATIONS:

After comparing numerous underwater oil recovery projects, it is evident that the most cost-effective and efficient methodology is typically a function of water depth, volume spilled and distribution of the pollutant. Surface-supplied diving is limited to relatively shallow depths due to decompression demands and safety considerations. Saturation diving systems are cost effective at intermediate depths, with the commercial saturation diving system during the *Jacob Luckenbach* oil recovery utilized at about 175 fsw. Remotely operated vehicles must typically be used at depths greater than 1,000 fsw and may also be cost effective at intermediate depths. For example, the SMIT/Frank Mohn PolRec system may operate in depths of greater than 8,000 fsw and, as demonstrated on the *T/V Prestige* operation, contractors such as Sonsub maintain ROVs that can operation in depths greater than 11,000 fsw. While atmospheric diving suits can operate beyond 2,000 fsw, their use during oil spill response operations has yet to prove operationally effective or cost efficient.

As the depths of recovery operations increase, the logistical requirements become more complex and dynamic. For example, a single experienced salvage contractor within a major U.S. port will likely be capable of managing a surface-supplied diving oil recovery operation. When the depth of the recovery requires use of a saturation system, numerous regional or national contractors must join the project team, since very few contractors maintain in-house capabilities to conduct every aspect of a saturation system diving supported underwater oil recovery project. The only option at greater depths, a remotely operated system, will likely require an international project team, with various system components being contracted from around the world. However, as Michel et al (2005) note *"Recent cases such as Prestige and Jacob Luckenbach have shown that there are few technological limitations to oil recovery from wrecks, even under very difficult situations"* (Michel et al, 2005).

All of the underwater oil recovery projects presented in this analysis were driven predominately by the Port States desire to eliminate a threat of pollution. In 1994, the National Research Council noted in their report, *A Reassessment of the Marine Salvage Posture of the United States*, that national governments had become proactive in handling vessel casualties that involve actual or threatened pollution, providing oversight, direction, and, often, active participation in the response effort (NRC, 1994). This finding holds true 20-years after the NRC assessment, with national governments driving pollution recovery efforts deeper below the surface and at greater distances from shore. This has been one of the largest changes seen in recent decades. It was not that long ago that a marine casualty that was submerged and not a hazard to navigation was considered of little significance. There is an increasing awareness that these casualties will eventually become a problem. The requirements from Port States to deal with the potential pollution from submerged wrecks have also become more stringent and expected.

In conclusion, today there is an expectation to respond immediately and decisively to any pollution incident, even if the pollutant is within a submerged vessel or on the bottom of the sea. Additionally, as shown in multiple case studies, if the pollutant remains within the vessel, technological requirements no longer pose a significant barrier to conducting recovery operations. Based on this analysis, the following recommendations are offered to further advance submerged oil detection and recovery efficiency and effectiveness:

1. Despite the time critical nature of marine casualty operations clearly articulated in the National Contingency Plan, and lessons learned from historical case studies, ship owners and operators are often reluctant to immediately deploy salvage assets to prevent ship casualties from deteriorating. Additionally, U.S. Coast Guard FOSCs are often not trained and experienced in salvage and submerged oil recovery operations. This is evident in the recent regulatory mandates and the need for guidance on vessel response plan activations, authorities and best practices (USCG, 2013). It is recommended that ship owners, operators and management companies, qualified individuals and regulatory officials seek formalized training in salvage operations to gain a better working knowledge of the tools and systems available to quickly respond to a vessel in distress.
2. The U.S. SMFF regulations should be amended to apply to vessels carrying Group V, non-floating oils. Additionally, the depth to recover oil outlined in the regulations should be extended well beyond the 150-foot parameter found within the definition of subsurface product removal. Revising the subsurface product removal response timeframes from 72 to 84 hours to more stringent timelines will encourage the continued development of more off-the-shelf systems to immediately address subsurface oil detection and recovery needs. Otherwise, advances in submerged oil detection and recovery will continue to be

episodic based on periodic large-scale events and industry will continue to have few financial incentives to move forward with additional research and design efforts.

3. Research and development studies should focus on both improving three dimensional subsurface oil spill trajectory modeling and oil detection systems. Advances have been made, as noted during the series of submerged oil symposiums following the *Deepwater Horizon* event, however these systems have yet to provide consistent results and are not readily deployable during a sub-surface response operation.
4. While there have been advancements in submerged oil detection and recovery, as highlighted during the *DBL 152* and Enbridge pipeline spills, there has been an absence in the development of techniques to effectively contain submerged oil, such as bottom boom, subsurface curtains and trenching techniques. Additional research and field testing should be conducted on effective methods to contain subsurface oil of various viscosities.
5. Finally, a national initiative to address the highest priority submerged wrecks identified in the NOAA RULET assessment should be considered. Such an initiative would further advance subsea oil detection and recovery techniques, and help in building submerged oil detection and recovery capabilities.

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