THE WEEPING MONUMENT:

A PRE AND POST DEPOSITIONAL SITE FORMATION STUDY

OF THE USS *ARIZONA*

by

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Major Department: Program in Maritime History and Archaeology

Since its loss on December 7, 1941, the USS *Arizona* has been slowly leaking over 9 liters of oil per day. This issue has brought about conversations regarding the stability of the wreck, and the possibility of defueling the 500,000 to 600,000 gallons that are likely residing within the wreck. Because of the importance of the wreck site, a decision either way is one which should be carefully researched before any significant changes occur. This research would have to include not only the ship and its deterioration, but also the oil's effects on the environment. This thesis combines the historical and current data regarding the USS *Arizona* with case studies of similar situations so a clearer picture of the future of the ship can be obtained.

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Photo courtesy of *Battleship Arizona* by Paul Stillwell

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by

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Chapter 1: The Day of "Infamy"

December 7, 1941 will forever be etched into history with Franklin D. Roosevelt's unforgettable words, "a date which will live in infamy"[1]. During the attack at Pearl Harbor, Japanese pilots sank and damaged numerous United States naval vessels. For many though, the most notable of these ships was the battleship USS *Arizona*, which is still lying on the harbor floor.

This thesis will pose the two-part question: Is the wreck of the USS *Arizona* in danger of structural failure on the bottom of Pearl Harbor, and what will be the ship's continuing legacy and effect on the harbor's environment? To answer this question I will begin with a pre and post depositional technical history of the USS *Arizona*, which will for the first time combine current information on the present condition of the hull and oil supply, with a complete history of the ship's upgrades and refits over time. Never before has corrosion analysis been combined with other current information and included with a thorough historical account of how the vessel evolved and was technically modified over time. This assessment allows a full appreciation of the potential hazard that the vessel may pose to the harbor's environment. In essence the thesis will focus on the mechanical history of the USS *Arizona* before, during, and after its sinking, investigating it not only as a historical site, but also as a case study in archaeological site formation, in order to describe this dynamic and potentially hazardous artifact.

The most notable event associated with the USS *Arizona* is of course the Japanese attack at Pearl Harbor. This, however, was only a moment within the ship's long and interesting history. Although the USS *Arizona* did not truly see battle action as a warship prior to its sinking

[1] K.D. Richardson, *Reflections of Pearl Harbor* (Connecticut: Praeger Publishers, 2005), xi.

in 1941, it was a mode of transportation for a president,[2] and the site of a Hollywood motion picture.[3] Multiple renovations were also performed on the ship during its lifetime, including many additions and subtractions to the hull and superstructure that modernized this warship and gave it additional capabilities. The extensive amount of historical information that will be included in this thesis gives a more complete and well-rounded history of the ship, one that reflects larger trends, both naval and political, of the interwar period.

When the USS *Arizona* was built in 1914, it was equipped to operate on oil rather than coal. The Navy Department made this decision for many reasons, both economic and strategic. Although there were many perceived tactical benefits of this change, it vastly limited the number of strategic ports that the ship could visit, and the presence of oil in its tanks continues to affect Pearl Harbor even now, over seventy years after the vessel's sinking.

Although the smoke has settled, the memories and feelings that are associated with the site of the USS *Arizona* live on, not only in the minds of veterans, but also of the average citizen, including many who may not have even been alive on that fateful day. Today, the USS *Arizona* memorial stands as a constant reminder of these strong feelings. The yearly visitation rate of approximately 1.5 million people clearly shows that the nation has not forgotten either the battle of Pearl Harbor, or the tragedy of the ship that has effectively become the icon of the entire disaster.[4] Visitors standing in the memorial designed by Alfred Preis are awestruck by the shadowy tomb lying barely visible in the dark water below.[5] Upon closer review of the site, many will notice the iridescent sheen of oil droplets floating to the surface. These have been

[2] Paul Stillwell, *Battleship Arizona* (Maryland: Naval Institute Press, 1991), 286.
[3] Ibid, 133.
[4] "USS Arizona Memorial," GORP, accessed August 24, 2010, http://www.gorp.com/parks-guide/travel-ta-u-s-s-arizona-memorial-hawaii-sidwcmdev_067976.html.
[5] Stillwell, 286.

dubbed the “tears of the *Arizona*”.[6] While symbolic of the brave men who did not survive, these “tears” are also a clear and perhaps ominous symptom of a larger problem. Since it sank in 1941, the USS *Arizona* has been slowly leaking oil. Legend states that the droplets will continue until the last survivor from the USS *Arizona* disaster has passed on.[7]

To the casual viewer, these slow drops may simply be a non-consequential part of the experience.[8] As of 2006, however, when 8 leakage points were measured, 9 liters were escaping on a daily basis (see figure 1).[9] In 1994 the observed loss of oil from the barbette #4 leakage site was only 1 drop every three minutes.[10] This single leak would equate to less than a 1 fluid ounce per day.[11] As figure 1 shows, however, this leak has grown to be an average of 1.2 liters during the years between 1994 and 2003.[12] Although the leakage rates have leveled off or in some cases decreased since 2003, these drops could possibly one day turn into a large release of oil that would be catastrophic not only in size but in its effects on the environment.

Naval reports state that on the morning of December 7, 1941, the USS *Arizona’s* tanks were completely full of oil.[13] This would mean that she was holding approximately 1.5 million gallons (5,678,117.68 liters) of heavy #6 bunker fuel oil.[14] Today it is generally calculated that the wreck is currently holding between 500,000 and 600,000 gallons (1,892,705.89 and

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[6] Dick Camp, *Battleship Arizona’s Marines at War: Making the Ultimate Sacrifice, December 7, 1941* (Minnesota: Zenith Press, 2006), 115.
[7] Priit J. Vesilind, "Oil and Honor at Pearl Harbor," *National Geographic*, 2001, pg. 86.
[8] Makinson et al, “In Situ Corrosion Studies on the USS Arizona,” *Materials Performance* (October 2002):2.
[9] Matthew A. Russell and Larry E. Murphy, "Long-term Monitoring Program: Structure, Oil, Artifacts and Environment," in *Long Term Management Strategies for USS Arizona, A Submerged Cultural Resource in Pearl Harbor* (Santa Fe, NM: Submerged Resources Center, 2008), 412-413, http://www.history.navy.mil/branches/UA_ManagementUSS%20Arizona-c.pdf.
[10] Bradley A. Rodgers, *USS Arizona's Oil; How Much Is There, Where Is It, and Can We Find It Before It Finds Us?*, proceedings of MOP Maritime Symposium, University of Hawai'i, Manoa (2000), pg. 5.
[11] "German American Corner: General Equivalent Guide," German Corner: German American Magazine and Business Guide, section goes here, accessed October 22, 2010, http://www.germancorner.com/recipes/hints/units.html.
[12] Russell and Murphy, “Long-term Monitoring”, 413
[13] MacKinnon Simpson. *USS Arizona, Warship. Tomb. Monument* (Hawaii: Bess Press, 2008), 112.
[14] “FAQ,” NPS.Gov, Accessed August 24, 2010, http://www.nps.gov/valr/faqs.htm.

2,271247.07 liters), which could potentially spill out into the small harbor if the hull of the ship were to collapse or if the tanks were catastrophically breached.[15]

The possibility of a catastrophic hull failure is of great concern for everyone involved with the conservation of the ship. Researchers associated with the National Park Service have, in the last decade, conducted intensive corrosion studies on the *Arizona.* According to this research, the corrosion rate is six times faster for the hull structure near the surface than for the structure below the mud line.[16] This is significant because sections of the wreck are buried in 25 feet of mud.[17]

The oil currently leaking from the *Arizona* originates from 11 sites throughout the ship, mainly located on the starboard side (see figure 2). [18] The oil that is escaping from the "B" sites is more weathered than the samples from the "A" sites. This means that the "B" samples generally have had more exposure to seawater, which intuitively shows that these drops are emanating from a location closer to the interior of the ship and thus have a longer distance to travel before collecting on the exterior of the hull.[19] This degraded oil is generally believed to be coming from secondary oil accumulated in spaces confined within the hull, not in the original oil tanks. These spaces perhaps lie under the main and upper decks where oil may have pooled and stayed for a period of time. The only unweathered oil originated from the leakage points near barbette #4, designated in figure 2 as "Location A". This oil most likely is leaking directly from

[15] Rodgers, 7.; Tim Foecke et al., "Investigating Archaeological Site Formation Processes on the Battleship USS Arizona Using Finite Element Analysis," *Journal of Archaeological Science* Xxx (2010): pg. 1.
[16] Foecke et al, 8.
[17] Donald Johnson et al., "Corrosion of Steel Shipwrecks in the Marine Environment: USS Arizona Pt. 1," *Materials Selection and Design*, October 2006, pg. 2.
[18] Amanda Graham, "An Environmental Study off USS Arizona Bunker C Fuel Oil," in *Long Term Management Strategies for USS Arizona, A Submerged Cultural Resource in Pearl Harbor* (Santa Fe, NM: Submerged Resources Center, 2008), 311, http://www.history.navy.mil/branches/UA_ManagementUSS%20Arizona-c.pdf.
[19] Ibid, 323.

the original oil tanks.[20] By obtaining information such as this, it should be simpler to determine ways to remove the oil if necessary, because it provides researchers with a better understanding of where the oil is originating.

The problem of an oil spill due to corrosion, or any other unforeseen event, could be mitigated in theory, although many issues surround this assessment. One such problem is that the oil tanks are currently buried in the harbor's floor at the bottom of the wrecked ship (see figure 3). This makes direct access to them impossible without significant dredging, which could potentially destabilize the wreck. This also means that the oil tanks located below the mud line are likely corroding at a fairly slow rate. In the event that access to the tanks became possible, removal would be made more difficult by the fact that the tanks are spread throughout three decks of the ship and separated by bulkheads. This attribute of the ship, which was originally a safety measure, makes removing the oil by inserting a minimal amount of hot taps impossible.[21]

Despite the difficultly that surrounds the removal of oil from the wreck, the effect on the environment that could occur from a catastrophic oil spill should not, and is not being ignored. The type of oil that is leaking from the ship is a thick bunker oil. This type of oil cannot evaporate as quickly as some lighter fuels and has shown to persist years after spills.[22] Even twenty years after an oil spill in Nova Scotia, Canada, from the tanker *Arrow,* bunker oil still saturates the surrounding sediment.[23] In this same light, the sediment around the USS *Arizona* was found to have components that also could be indicative of oil contamination.[24]

The relatively small amount of oil that is presently leaking from the ship is partially degraded by sediment microbes around the ship. These organisms would not be able to break

[20] Russell and Murphy, "Oil Removal", 406-408.
[21] Russell and Murphy, "Long-term Monitoring Program" 391-392.
[22] Rodgers, 5.
[23] Graham, 352.
[24] Ibid, 373.

down a massive amount of oil that would be released during a catastrophic hull failure.[25] Despite this, the water surrounding the wreck has been visually identified as improving because of increased visibility and the recent appearance of yellow seahorses which are vulnerable to pollution.[26] However, no continuous quantitative data of the surrounding environment have been recorded since 1988, because of financial restrictions.[27] This makes it difficult to know the current impact of oil on the environment. For this reason, I hope to use comparative case studies to analyze the most likely effects of bunker oil spills. At the moment, the National Park Service's decision is that because the wreck is a war monument and logistical issues would complicate removing the oil that their studies have shown is having a negligible effect on the environment, the possible impacts should be remediated, and the oil should not be removed.[28]

The importance of the *USS Arizona* is an undeniable fact both historically and as a potentially hazardous artifact. To fully analyze the ship, historical information must be combined with current research concerning the degradation of the hull and superstructure, the oil leakage, and the effects on the environment. Each of the subjects presented here are completely explored in later chapters, thereby informing the reader of the site formation processes that make this artifact as potentially dangerous to the surrounding environment as it is historically significant.

To begin this narrative, it is important to point out that, like any active human system, the USS *Arizona* was constantly changed and upgraded. The vessel that exploded and subsequently sank on December 7th 1941 was not the same battleship that was launched in 1915. The

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[25] Ibid, 375
[26] David Lindsay, "Seahorses: Flagships of Our Coasts," CSA.com, May 2003, Threats to Seahorses, accessed April 10, 2012, http://www.csa.com/discoveryguides/seahorses/overview.php.
[27] Russell and Murphy, "Long-Term Monitoring Program", 421.
[28] Matthew A. Russell and Larry E. Murphy, "Oil Removal Versus Site Preservation," in *Long Term Management Strategies for USS Arizona, A Submerged Cultural Resource in Pearl Harbor* (Santa Fe, NM: Submerged Resources Center, 2008), 421, http://www.history.navy.mil/branches/UA_ManagementUSS%20Arizona-a.pdf.

following will explore both the original construction and the technical improvements that this historical ship underwent during its lifetime.

Ship's History

A chill was in the air on March 16, 1914. Gathered at the New York Naval Yard were hundreds of spectators awaiting the ceremony surrounding the construction of a new American battleship. At this point the ship was unnamed, known only by its battleship designation number, BB-39.[29] This was to be the second of the Pennsylvania class ships.[30] Once the Assistant Secretary of the Navy, Franklin D. Roosevelt, arrived in his derby hat, the bands began to play and the guns fired a salute.[31]

The first materials for the ship were ordered on September 18th, 1913 and, although the keel had not yet been laid, construction had already begun on some of the hull plating.[32] The keel being laid on the morning of the ceremony was comprised of three fifty-foot long plates. During the festivities, these were temporarily connected with nickel bolts placed by five young sons of naval officers. Henry Williams Jr., whose father was a naval constructor, was one of the boys chosen. For reasons not completely clear, the young boy was drawn to Roosevelt. Williams stated later about the event, "I grabbed his finger and hung on for dear life. And they tried to get me away, and, of course, I was a little ham. FDR, being a bit of a ham himself, I guess he saw the possibilities or whatever it might be for all the picture taking…So…he shooed them away, and I stayed hanging onto his hand" (see image 1).[33] Because of the sudden publicity, Williams was given the honor of placing the first bolt. These bolts would later be

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[29] Stillwell,3.
[30] Daniel A. Martinez, "USS Arizona," in *Submerged Cultural Resources Study USS Arizona Memorial and Pearl Harbor National Historic Landmark* (Santa Fe: Southwest Cultural Resources Center Professional Papers No. 23, 2001), 24.
[31] Stillwell,3.
[32] Norman Friedman et al., *USS Arizona (BB39)* (Annapolis, MD: Leeward Pub., 1978), 4-6.
[33] Stillwell,4.

replaced by steel rivets, with the nickel bolts being given back to the boys as a souvenir.[34] The rivets permanently hammered into the ship's keel remain today, holding together the twisted remains of the *Arizona.*

After the festivities had concluded, the real work began. Only one day after the ceremony ended, the ship was already beginning to take shape. One-hundred and fifty frames were placed, each spaced four feet apart. Once the final rib had been attached on April 2, 1913, the workers began to construct the athwartship bulkheads, thus creating watertight spaces throughout the ship. As was previously mentioned, the remains of these bulkheads are still affecting the ship today. Two months after the bulkheads were completed, some of the largest components, including the stem and stern posts, were installed. Approximately 6,000 tons of armor plating was also attached to the ship at this time. Finally, on May 20, 1915, one of the final components, the all-important rudder, was attached. Only 14 months after the keel was laid, the USS *Arizona* was nearing completion.[35]

Although its class and designation number were known, the ship still did not have an official name. On June 19, 1915, the USS *Arizona* was pushed into the water and the naming ceremony began. A law passed by Congress in 1898, determined that all battleships be named after states.[36] For this newly built ship, the honor was given to the 48th state, which at that point was the newest in the union.[37] Arizona had become a state only years earlier on St. Valentine's Day 1912.[38] Esther Ross, a descendant of one of Arizona's pioneer families, was chosen to christen the vessel the USS *Arizona* (see image 2).[39]

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[34] Ibid.
[35] Friedman et al., 4.
[36] Simpson, 6, 15.
[37] Daniel J. Lenihan, ed., *Submerged Cultural Resources Study: USS Arizona Memorial and Pearl Harbor National Historic Landmark* (Santa Fe: Submerged Cultural Resources Unit, Southwest Cultural Resources Center, 1989), 24.
[38] Stillwell, 9.
[39] Ibid, 4-10.

The ship had been launched, but it had not yet been completed. Some of the components of the ship, such as the turrets and guns, were yet to be added. The installation of the ship's main armor belt was also postponed, as the additional weight could have been detrimental to the launching ramp.[40] Even after the ship was fitted out, it was months before the *Arizona* was officially commissioned because it had not yet undergone sea trials.[41]

The USS *Arizona* was commissioned on October 17, 1916, costing the Navy 16 million dollars and two and a half years in construction. John D. McDonald was chosen to be the first commanding officer of the newest American battleship. He had received his training at the Naval Academy, where he graduated in 1884. In total, McDonald had thirty-two years of service before he took on the responsibility of commanding the historic ship.[42]

The USS *Arizona* was the second of the two Pennsylvania class ships that were built. Although this class was similar to the earlier Nevada class ships, the plans for the Pennsylvania class had called for an even larger, faster, and more heavily built warship.[43] Both Pennsylvania class ships, the *USS Arizona* and the *USS Pennsylvania*, were built on the East Coast of the United States and were involved in Pearl Harbor. Although the *USS Arizona* was sunk in the attack, the *USS Pennsylvania* was repaired and later served in the Pacific theater of World War II.[44]

When completed, the USS *Arizona* was 608 feet long, with a beam of 97 feet, 1 inch. Its draft was 28 feet 10 inches and in total, the ship displaced 31,400 tons.[45] Combined with the weaponry, these attributes made the *USS Arizona* a powerful battleship during that era (see

[40] Friedman et al, 4.
[41] Ibid.
[42] Stillwell, 12.
[43] Friedman et al., 4.; Department of the Navy, 2001.
[44] Department of the Navy, 2001.
[45] Martinez, 24.

figure 4). In the U.S. Navy, the Pennsylvania class ships were second only to the New Mexico class in total displacement and length.[46] The USS *Nevada,* which had been built one year earlier, had a displacement of only 27,000 tons, and was 33 feet shorter than the *Arizona*.[47] The *Arizona's* overall size, strength of battery, and all turbine engineering made this vessel one of the United States' first super dreadnoughts.[48]

The firepower housed on the USS *Arizona* was another improvement over many other battleships built around the same time. The *Arizona* was outfitted with twelve 14-inch/45 caliber guns.[49] Comparatively, the British dreadnought *Queen Elizabeth* (BB-9), built in 1913, had four double turrets equipped with eight 15-inch/42 caliber guns.[50] Caliber on warships at that time was a measurement of length, and specifically refers to the length of the gun barrel as multiples of the bore diameter. To determine the actual length of the barrel, the bore diameter of 14 inches is multiplied by 45, the caliber, indicating a 630-inch (52.5 foot) long barrel.[51]

The 14-inch/45 caliber guns were mounted in four triple turrets, two aft, and two forward.[52] The term "triple turret" means each had three barrels that fired at nearly the same time. Because there was a danger of the middle shell colliding with the other two midair, the center barrel was timed to shoot a fraction of a second later than the outer two.[53] These main guns could fire a 1,500-pound artillery shell 23,000 yards, a process that required four 100-pound silk bags of gunpowder. When fired, the massive shells turned one full clockwise rotation

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[46] Jane's Publishing Company, *Jane's Fighting Ships of World War I* (London, Eng.: Studio Editions, 1990), 133-136.
[47] Martinez, 40, Michael Mohl, "BB-39 USS Arizona," NavSource Online: Battleship Photo Archive, Pennsylvania Class Battleship, accessed August 24, 2011, http://www.navsource.org/archives/01/39a.htm.;
[48] Joy Waldron. Jasper, James P. Delgado, and Jim Adams, *The USS Arizona: the Ship, the Men, the Pearl Harbor Attack, and the Symbol That Aroused America* (New York: St. Martin's Press, 2001), 27; Stillwell, 4.
[49] Lenihan, 24.
[50] Janes, 35.
[51] Richard D. Camp, *Battleship Arizona's Marines at War: Making the Ultimate Sacrifice, December 7, 1941* (St. Paul, MN.: Zenith Press, 2006), 19.
[52] Friedman et al., 10-11.
[53] Simpson, iii.

for every 37.3 feet of forward momentum. This was due to the rifling in the barrel, which greatly improved the gun's accuracy.[54] The USS *Arizona's* large firing capacity gave the battleship a 13,500 pound salvo weight. This placed the *Arizona* on par with the most powerful battleships of any foreign power at the time.[55]

The turrets housing the 14-inch guns were heavily built and set on cylindrical armored barbettes that extended deep into the hull of the ship.[56] To operate each of the ship's turrets, 25 men had to be inside the section visible above the deck, also known as the gunhouse, while 45 men worked the artillery hoists and magazines below.[57] Each gunhouse rotated separately on bearings on the rim of the barbettes, which served as shelter for the shells, powder hoists, and the gun's elevating machinery.[58]

Although the main turrets contained the most powerful guns, the USS *Arizona* also had supplementary batteries. The battleship was equipped with twenty-two 5-inch/51 caliber guns.[59] Surrounding each 5-inch gun was an individual 12x20 foot casemate with a convex outer bulkhead. When not in use, canvas covered the openings, except in inclement weather when metal doors with rubber gaskets created watertight seals.[60] These guns provided protection from torpedo boat attack, and were methodically placed to cover all possible low angles. To achieve this, two of the guns were placed next to the conning tower, eight were mounted under the forecastle deck on both the starboard and port sides, and the final four were divided between the two sides of the second deck near the stern.[61] Aiming the 5-inch guns at horizontal angles of 90 to 120 degrees was possible, but, because of the restrictive openings in the casemates, the guns

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[54] Friedman et al., 25.
[55] Friedman et al.,10-11.;Camp, 19.
[56] Ibid, 10-11.
[57] Camp, 19.
[58] Friedman et al., 10-11.
[59] Ibid, 11.
[60] Camp, 20.
[61] Friedman et al., 11.

could only be raised to an elevation of 20 degrees.[62] The low angle of elevation and the slow operating time made these 5-inch guns ineffective against aircraft.[63]

In 1917, the U.S. Navy installed four 3-inch/50 caliber guns on the ship to help remedy the problem caused by the lack of anti-aircraft guns. Half of the new guns were mounted on the No. 3 turret, while the other two were placed on the forward deckhouse. These guns were chosen because their 50 caliber shells were large enough to create both an explosion and shrapnel sufficient to take down a plane.[64]

In addition to the superstructure guns, the USS *Arizona* was built with two underwater torpedo tubes. Originally, the Pennsylvania class ships were designed to have four tubes, but half were removed from the *Arizona's* plans before construction. The remaining torpedo tubes were placed on either side of the ship, below the waterline. While the effects of a direct hit from a torpedo would be substantial, the battleship was not sufficiently maneuverable to effectively deliver the weapons. This was mainly due to the long lag time between release of the torpedo and its impact with the proposed target.[65]

The ship that housed the aforementioned guns was built with a ram type bow. This bow had sharp ends that reached the upper decks and quickly flared out to be rounded. This shape cut down on water resistance, thereby increasing the ship's speed. The stern was a "cruiser" type, equipped with one semi-balanced rudder.[66] A cruiser stern was traditionally used on battleships of the era because the sharp curve up from the waterline ensured that the rudder would be continually submerged while the ship was under normal loads. This was essential, as an exposed

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[62] Camp, 20.
[63] Friedman et al., 11.
[64] Ibid.
[65] Ibid, 12-27.
[66] Ibid, 6-8.

rudder would quickly become a target.[67] The hull itself was constructed of steel frames laid at 90° from the keel, in the traditional shipbuilding manner. The frames braced three decks within the hull, extending the length of the ship at a consistent height. The uppermost main deck was utilized as both crew housing and protection for the machinery associated with the windlass. This was possible because the forecastle deck extended from frame 88, just forward of the mainmast, to the bow, thus protecting the main deck below.[68]

As originally built, the tallest points of the USS *Arizona* were the two cage style masts extending from the deck (see image 3). The masts became wider as they descended toward the deck, which increased the strength of the structure. Along the masts, at specific elevations, were wire gratings that created landings with attached ladders. This allowed sailors access to the eight searchlight areas and spotting tops. At the top of each of these masts was a variety of equipment including the spotting area, yardarms, antenna supports, searchlight platforms, and torpedo control platforms.[69]

Attached aft of the No. 2 turret was the armored conning tower. This was built high enough to allow the flag officers to see past both the stern and forward turrets. Each side of the tower had three viewing ports, and was armored with 16 inches of case hardened steel. The forward end of the interior conning tower housed the ship’s control, while opposite this was the fire control. Attached to the starboard, port, and aft sides of the conning tower was a bridge. Below this bridge was an open-wing chart house that surrounded an enclosed chart table. The

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[67] "Glossary -- 'Cruiser' Sterns," Naval History and Heritage Command, March 14, 2007, accessed September 26, 2011, http://www.history.navy.mil/photos/glossary/glos-c/cru-strn.htm.
[68] Friedman et al, 6-8.
[69] Ibid, 10.

conning tower and associated bridges were supported by both the forward deckhouse, and three longitudinal and transverse bulkheads that extended down to the armored deck.[70]

Attached to the superstructure deck were two deckhouses. The first of these was attached to the No. 2 barbette, on the aft end. Contained within this deckhouse were many necessities of shipboard life. The starboard side of this structure held the Captain's stateroom, while opposite this, on the port side, was the bakery. The addition of this deckhouse also protected the communication tubes from damage.

The aft deckhouse, much like the bakery in the forward structure, was mainly food related. Contained here, located between the stack and the end of the forecastle deck at frame 88, was the butcher's shop, crew galley, and perishable storage. Aft of frame 88, the main deck was unprotected and thus called the quarterdeck for the sake of differentiation.[71]

Below the main deck, the second deck had many uses, mostly associated with crew necessities. Starting at the No. 1 barbette and continuing forward was the area designated for the Chief Petty Officers' cabins, as well as the sickbay. Aft of this area was the laundry, carpenter's shop, and shipfitters. The majority of the men lived within the midships area of the *Arizona*, with the officers living aft of frame 91.[72]

Deck three was the location of most of the ship's storerooms. Also included on this deck were the boiler uptakes and ammunition passages. Beneath the third deck were two additional sub-decks, which were connected between the machinery spaces, and the respective forward and aft ends of the ship. The lowest deck was the engineering hold where the heavy machinery and engines were housed.[73]

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[70] Ibid, 9-10.
[71] Friedman et al, 6-8.
[72] Ibid, 6.
[73] Ibid.

The *Arizona's* original eight Parsons turbines were located within the deepest area of the ship.[74] Along with the turbines were twelve Babcock and Wilcox boilers. These were an oil-powered watertube type. Each boiler had a heating surface of 6,916.5 square feet, for a combined total of 55,332 square feet. As originally constructed, 313.5 tons of reserve water and 2,332 tons of fuel oil were contained within the ship.[75] These turbines and boilers provided the ship with 33,375 horsepower and a top speed of 21 knots.[76] Comparatively, the slightly larger *New Mexico* class ships produced between 27,500 and 32,000 horsepower.[77]

While different combinations of the available turbines were used depending on the battleship's situation, it is clear that American engineering design was in the experimental stage and likely not as advanced as the British Royal Navy. Speeds below seventeen knots used the two cruising and low-pressure turbines connected to the outboard propeller shafts.[78] Each of these shafts had their own engine room located below the mainmast.[79] Between these two engine rooms was a third, housing the two inboard shafts, controlled by an equal number of high-pressure turbines. This setup was not highly efficient. Whenever the ship went astern, there was no way to stop the ahead low-pressure turbines, and vice versa. In addition, while moving at lower speeds, the boiler steam had to pass through the cruising turbines before it went through the high and low-pressure turbines. At higher speeds though, the steam was shunted around the cruising turbines which created a more efficient cycle. The lack of a clutch system to disengage some of the turbines while engaging others did not allow for efficient fuel-oil usage.[80]

[74] Stillwell, 14.
[75] Friedman et al., 16.
[76] Lenihan, 24.
[77] Janes, 133.
[78] Stillwell, 16-17.
[79] Friedman et al., 15.
[80] Stillwell, 16-17.

The direct drive turbine system was at times the least of the problems associated with the turbines. While performing maneuvers on the York River, Captain McDonald called for the turbines to reverse at full speed and was surprised when the chief engineer, Lieutenant Commander Harold G. Bowen, did not protest. When later asked about the incident, Bowen commented, "Everyone knew the *Arizona* was no good and the sooner the turbines were completely busted up and some new ones put in the better it would be for everyone."[81] It was even said that a favorite sport of the sailors was listening for the rubbing of the turbine blades. On December 7, 1916, soon after the commissioning of the ship, and twenty-five years to the day before the USS *Arizona* would be destroyed, the blades of the starboard low-pressure turbine were stripped. The repairs for this problem forced the vessel to stay in New York Navy Yard for three months.[82] The changes to the ship were time consuming and expensive. To repair the problem, large areas of the top decks had to be removed to allow the crane room to lift out the blades. The items were then taken to a machine shop, repaired, and replaced.[83]

Although the ship left the yard in March 1917, the problem was not truly solved. The vessel's chief engineer, Bowen, made it his mission to solve the issues associated with the turbines. After inspecting the machinery and the blueprints associated with them, Bowen came up with an amazingly simple solution to what had become a costly problem. After obtaining permission from the Bureau of Engineering, Bowen shaved .02 of an inch off the rotor and all the blades of one of the problematic turbines. This small change eliminated the rubbing, the possibility of damage, and added fuel efficiency. After seeing the beneficial results, the rest of the ship's rotors and blades were shaved in the same manner. This change helped to stem

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[81] Ibid, 28.
[82] Ibid.
[83] Ibid, 20.

significant problems until the turbines were replaced in 1929 during one of the modernizations of the ship.[84]

The fuel oil needed to power the turbines created additional problems for the ship. Although the USS *Arizona* had just been built, it was unable to fight in World War I because of the lack of oil in Europe. In 1917, five American dreadnoughts, the *Texas, Wyoming, New York, Delaware, and Florida,* were all relocated to the British Isles to assist in the fight against the German fleet. The dreadnoughts that were sent were all coalburners. Instead of steaming to Europe, the *Arizona* was stationed on the Chesapeake Bay and used as a gunnery-training vessel for the men who would then be placed upon commercial and naval escort ships which would fight in World War I.[85]

As described, the USS *Arizona* was one of the United States' first oil-fueled battleships.[86] The ship's tanks held a maximum of 2,332 tons (approximately 596,992 gallons) of this precious commodity, contained within 200 bunkers throughout the ship.[87] Originally, the *Arizona* had the capability to travel approximately 4,000 miles. This would be extended later in the ship's life to reflect its mission as an oceanic patrol and combatant. Although the choice of oil as a fuel type would be an issue that would plague the ship even to this day, the distance the ship could travel without refueling was impressive. Comparable English battleships of the time were only able to travel approximately 400 miles without refueling.[88]

The coal needed to power other ships has, since the beginning of the age of steam, betrayed them by sending up black plumes of smoke through the stacks, alerting all within sight

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[84] Ibid, 28.
[85] Stillwell, 22.
[86] Friedman et al., 33.
[87] Friedman et al., 16; "How Much, For What, and Ending Up Where?," Global Marine Oil Pollution Information Gateway, Oil Entering the Marine Environment, accessed September 26, 2011, http://oils.gpa.unep.org/facts/quantities.htm.
[88] Friedman et al., 2-3.

of their presence. In addition to this, coal was highly detrimental to the health of the engine crew, otherwise known as the "black gang."[89] Coal-fueled ships had to be refueled every couple of weeks. This grueling process took multiple days, including additional days of cleaning to remove all of the fine coal dust which inevitably covered every surface.[90]

Likely however, the most influential of the reasons for the transition to oil was economics. The number of firemen needed on an oil-fueled ship could be reduced by up to 70 percent. This was a reduction, not only in paychecks, but also in how many men were fed at the end of each day. Oil-powered ships also had the capability to carry more cargo if needed because they were more efficient, as oil generates more British Thermal Units (BTUs) than coal. In addition, oil took up less space within the ship than did an equal amount of coal. Approximately six tons of oil could do the same job as ten tons of coal.[91] A metric ton of coal will produce 22.9 million BTUs, while an equal metric ton of fuel oil will create 42.5 million BTUs. That is nearly an 86 percent increase in productivity.[92]

While the decision to construct an oil-based battleship may have initially made the *Arizona* modern, many modifications throughout the ship's lifetime changed its physical appearance. One of the first major overhauls that the ship underwent began in 1919.[93] Between June 1919 and January 1920, the USS *Arizona* remained in the New York Naval Shipyard for maintenance and upgrades.[94] At that time the two cage masts were equipped with fire-control tops, built by removing the V-shaped front screens and replacing them with new octagonal

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89 Rodgers, 5
90 Simpson, 16
91 "Supply of Fuel Ample, Expert Says," *The New York Times*, July 11, 1920, accessed August 24, 2011, http://query.nytimes.com/gst/abstract.html?res=9A02E0DD103FE432A25752C1A9619C946195D6CF.
92 Simpson, 16
93 Stillwell, 31, 48.
94 Lenihan, 25.

torpedo defense systems. This addition was appreciated by the sailors as the roof and windows gave the men more protection from the elements. [95]

Although the years between 1921 and 1928 were generally routine for the men living onboard the ship, it was renovated again in 1925. During the three-month process, many changes occurred that affected the hull and superstructure of the battleship. One of the most apparent changes was the addition of an airplane catapult on the stern of the ship. The catapult operated on compressed air. Ironically, this instantly made the catapult obsolete, as the newer systems used powder charges that launched the planes at a much faster rate.[96] The USS *Arizona*'s less efficient compressed air catapults could only launch small planes in ideal weather conditions. This however was only half of the problem. The planes, once launched from this less efficient system, were unable to return to the ship and instead had to land ashore. This restricted the amount of information the pilots could easily report back after missions.[97] In later years, the ship was updated to have not only more efficient catapults, but also a crane to lift the planes back onto the ship after making a water landing.[98]

Many of the USS *Arizona's* other 1925 renovations were focused on improved weaponry and crew work areas. New 5-inch and 14-inch guns were installed with hydro-pneumatic counter-recoil systems. A new plotting room was also built so the guns could be more accurately aimed. Gun turret rooms were made safer with the installation of sprinklers, which prevented a fire from engulfing the rest of the ship. The navigation bridge, which had formerly been bitterly cold and uninhabitable during the winter, was improved with the addition of bulkheads to

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[95] Stillwell, 48.
[96] Ibid, 87.
[97] Friedman et al., 17.
[98] Jasper et. al., 39.

enclose the area and make it more hospitable for the men.[99] Lastly, in the engineering department, six hundred tons of fuel-oil were added to the ship's capacity. The ship could now steam approximately 9,000 miles while cruising at ten knots.[100]

Three years before the *Arizona's* 1925 renovations, the Washington Naval Limitations Treaty began to greatly affect the lives of battleships built around the turn of the century.[101] Under the provisions of this treaty, a battleship was deemed out of service 20 years after it was built. When construction on the replacement ship was completed, the former would be decommissioned. Taking into account the amount of time required to build a new battleship, the USS *Arizona* could have been decommissioned around 1940, one year before the ship was lost at Pearl Harbor. Instead, many ships like the *Arizona* were modified to bring them up to the current standards, thereby postponing decommission. The treaty allowed for an addition of 3,000 tons to the ships to modernize them. Because of the time frame, construction was begun on the oldest ships first, with the USS *Arizona* not being authorized for updates until February 25, 1929.[102] On May 4 of that year, the ship returned to its original home port of Norfolk to undergo the largest of its overhauls. It remained there under reduced commission until July of the same year.[103]

Many changes were made to the superstructure of the ship during this modernization. An additional forecastle deck was added, which spanned from the No. 2 turret aft until the break at frame 88. Above this superstructure deck, a new flag bridge and deckhouse were also built. Even though the USS *Arizona* was a divisional flagship, prior to the modernization of 1929, the ship had not had a sufficient bridge. The new structure had multiple levels, making it one of the

[99] Stillwell, 87-88.
[100] Ibid.
[101] Ibid, 110.
[102] Friedman et al., 21.
[103] Lenihan, 25.

taller points of the ship, and allowing the captain better visibility. An emergency platform with both a chart house and sea cabins for the flag and chief of staff were also built above the main bridge. Above this was a navigation bridge, with a range-finding platform located on top. [104]

One of the most visible changes during the 1929 modernization was the removal of the ship's cage masts. These were replaced by the more modern fore and aft tripod type.[105] This update occurred partially because the older cage masts were known to sway dramatically after a turret gun salvo, and could be significantly damaged in heavy seas. The newly installed tripod masts were more utilitarian and stable.[106]

Attached to the outside of the ship in 1929 was armor in the form of blisters. These protected against the possibility of a torpedo attack, and made the ship more stable (see image 4).[107] Each blister was composed of 70-pound specially treated steel.[108] In theory, if the ship were to be hit with a torpedo, the warhead would explode upon impact with the blister thus protecting the vital internal components. These blisters were constructed of four separate tanks. The two central tanks were filled with oil, whereas the exterior and interior tanks were kept empty to create a barrier between any torpedoes and vital areas of the ship.[109] By adding oil to the two central tanks, the available fuel capacity grew from approximately 2,932 tons to 4,630 tons. [110] In emergency situations, this could be increased to 6,180 tons. This allowed the ship to travel 13,600 nautical miles at 15 knots, 8,850 miles further than before the fuel enlargement.[111] The addition of the armor blisters also increased the beam of the ship from 97.5 feet to 106 feet

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[104] Friedman, et al., 26-28.
[105] Lenihan, 25.
[106] Stillwell, 111.
[107] Friedman, et al., 22.
[108] Stillwell, 109-110.
[109] Friedman et al., 24.
[110] Lenihan, 25-29.
[111] Friedman et al., 22.

$2^{3/4}$inches.[112] If the ship was any wider, it would be unable to pass through the Panama Canal, which was only 110 feet wide.[113]

The added stability and floatation provided by the torpedo blisters allowed for more armor to be installed on the superstructure. The ultimately legitimate fear of an air-based attack also led to additional armor being placed below the upper decks.[114] Two inches were added to the main deck to protect the armor deck within, while one inch was added to each turret top to protect the ship from overhead attacks. This meant that five inches of armor were now protecting the main deck. However, since this armor resided in two layers, it was not equivalent to a solid 5-inch plate.[115]

The changes to the ship's superstructure were not solely beneficial. Because the hull shape was changed, the battleship's top speed was decreased by 0.3 knots.[116] Another problem with the 1929 additions was the significant amount of weight added to the ship. To compensate for this, new turbines and Bureau Express three-drum boilers were installed.[117] The new boilers were more efficient and three alone could do the work of the previous twelve. The turbines that the *Arizona* obtained were inherited from the *Washington*, since work on that ship had ceased after the 1922 Washington Treaty.[118]

The USS *Arizona's* guns were also affected by the 1929 renovation. The 5-inch/51 caliber guns originally attached to the ship were less useful after tactical changes that had occurred between World War I and World War II. Originally, the fear of attack came from water launched torpedoes. By the time of the 1929 modernizations, the tactics favored air-based

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[112] Ibid, 22.
[113] Stillwell, 110.
[114] Lenihan, 25.
[115] Friedman et al., 22-23.
[116] Ibid, 22.
[117] Lenihan, 25-29.
[118] Stillwell, 110.

torpedo attacks. The original 5-inch/51 caliber guns were attached to the ship at such a low angle that they were rendered useless whenever any amount of weather occurred. For these reasons, only 12 of the original 5-inch/51 caliber guns were left on the ship after modernization. The remaining guns were either moved up a deck and enclosed in the newly built superstructure deckhouse or placed next to the conning tower.[119]

The USS *Arizona* was also equipped during this time with eight 5-inch/25 caliber guns. These were mounted equally on either side of the newly built superstructure deckhouse. Each of these semi-automatic guns was placed in a way that allowed them to aim at both air and surface targets.[120]

During the reconstruction of the ship, eight .50 caliber heavy machine gun mounts were installed high on the tripod masts, although the actual guns were not added to the ship until 1933. Modeled after the highly successful Browning water-cooled gun used in World War I, the .50 caliber guns had a high fire rate and ease of use, which made them perfect for bringing down aircraft.[121]

The last armament change occurring during the modernization of 1929 was the removal of the torpedo tubes. As previously mentioned, the USS *Arizona* was originally designed with four tubes; however, by the time she was actually constructed, the ship was only built with two. The amount of space the torpedo rooms occupied prompted the Navy to remove them. These rooms interrupted the continuous line of the side protection system, making the ship more vulnerable to attack. After removal, the area previously containing the torpedo rooms was subsequently integrated into the ship's armor blister.[122]

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[119] Friedman, et al., 26.
[120] Ibid.
[121] Ibid, 27.
[122] Ibid.

Although the USS *Arizona* was overhauled five more times between 1934 and 1941, only minor changes occurred. The Emergency Anti-Aircraft Improvement Program required four mounts for the newly produced 1.1-inch guns on every ship that would be operating in the Pacific. On the USS *Arizona*, two 5-inch/51 caliber guns that had previously been mounted on either side of the conning tower were removed in favor of the new 1.1-inch anti-aircraft guns. Although foundations, ammunition hoists, and ready service lockers were built to accommodate these guns, neither the mounts nor the guns themselves were ever installed.[123]

The final changes that occurred on the USS *Arizona* involved the .50 caliber weapons. These anti-aircraft guns were relocated multiple times, but by the time of the Pearl Harbor attack, the guns were placed in the following configuration. Two .50 caliber guns taken from the mainmast replaced four of the searchlights, while another four were installed on the newly created "bird's nest" platform on top of the mainmast's director tower. The four searchlights that were removed were placed on the mainmast (see image 5).[124]

The Attack

At the time of the USS *Arizona's* final modifications, the ship had already relocated to the United States Pacific Fleet due to increased Japanese hostilities.[125] In 1937, Japan invaded and viciously attacked China. Horrified, the United States watched the atrocities being committed against the Chinese people. Later the same year, the Japanese further damaged relations with America when they bombed and sank the American gunboat *Panay*, afterwards explaining it away as an accident. As aggressions heightened in 1940, the Japanese allied with the German and Italian forces. This move encouraged President Roosevelt to place an embargo on imported Japanese supplies, such as steel, gasoline, and oil. In addition to this, Roosevelt

[123] Ibid, 26-30.
[124] Friedman, et al., 30.
[125] Stillwell, 69; Friedman et. al,. 33.

moved the Pacific Naval Fleet to Pearl Harbor, hoping its presence would discourage further Japanese aggression.[126]

Sadly, this was not the case. The Japanese Commander-in-Chief of the Combined Fleet, Isoroku Yamamoto, prepared detailed plans for an assault on Pearl Harbor. Yamamoto knew that the Japanese would not be able to fight a long-standing war with the United States and would need instead to rely on a devastating first strike, thereby taking the American forces by surprise. Yamamoto's plan involved the use of carriers to transport the attack force, backed by submarines and secondary midget subs, both of which would quietly launch when they neared the Hawaiian Islands.[127]

At 7:53 a.m. on December 7, 1941 Japanese planes flew over Pearl Harbor. Within the next thirty-two minutes, twenty-seven dive bombers and twenty-four Japanese torpedo planes were attacking Ford Island and Pearl Harbor. The *Pennsylvania* was the first vessel hit during the attack and it caught fire. Ship after ship was hit, causing extensive damage. The Japanese were not only targeting ships though, air strips, hangars, and civilian sites were also under attack.[128]

At the time of the attack, the USS *Arizona* was berthed in the F-7 slot, alongside the repair ship USS *Vestal* (see image 6).[129] At 8:05 a.m., as the men rushed through the ship, a 500-pound bomb dropped onto the *Arizona*. It exploded in the flag officer's pantry, after glancing off the No. 4 turret and penetrating the deck. The men who were in the No. 3 turret remember best the sparks and sickening gas emitted from the compartment after the bomb went off.[130]

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[126] Waldron et. al., 91-93.
[127] Richard A. Wisniewski, *Pearl Harbor and the USS Arizona Memorial: a Pictorial History*, 3rd ed. (Honolulu, Hawaii): Pacific Basin Enterprises, 1986), 19-21.
[128] Camp, 75-82.
[129] Martinez, 30.
[130] Camp, 84.

Five Japanese Nakajima B5N (aka Kate) bombers, flying in a “V” formation, attacked the battleship *Arizona* and the adjacent repair ship USS *Vestal*.[131] Included in this group, and flying at over 10,000 feet, was Lieutenant Shojira Kondo, who released an armor piercing bomb from his plane. It struck the forecastle deck on the starboard side before ripping through four decks near the No. 2 turret and exploding.[132] This bomb is generally credited as the death blow to the *Arizona*.[133] Those who were spared remember the bomb making a very distinctive sound. Private First Class James Cory recalled: “The bomb struck forward of us. You could feel it penetrate the decks and then there was this big ‘Whoosh!’ Now it wasn’t a Bang. It wasn’t a Boom. It was a Whoosh!”[134] As the bomb hit, men stationed on other vessels recall seeing bodies thrown into the air.[135] William Goshen was on the USS *Arizona* when this bomb hit. He remembers being thrown into the air and landing in the dangerous waters below. Although he survived, 70 percent of his body was covered in flash burns.[136] Although, in many cases, they were burned beyond recognition, it is possible that during one of the explosions some of the men from the USS *Arizona* were even thrown onto the decks of the nearby USS *Vestal*.[137]

If the bombs had not created enough damage by themselves, their positioning secured the fate of the *Arizona*. Many believe that as the explosion from Lieutenant Kondo’s bomb ripped through the ship, it ignited the *Arizona’s* 582 tons of 14-inch ammunition and fuel.[138] The fire burned hot, killing and maiming sailors as it quickly moved through the ship. James Cory remembers watching the burned and half-dead men walk through the decks like zombies. He

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[131] Kent Budge, "B5N "Kate," JapaneseTorpedo Bomber," B5N "Kate" Japanese Torpedo Bomber, accessed October 24, 2011, http://pwencycl.kgbudge.com/B/5/B5N_Kate.htm.; Camp, 89.
[132] Camp, 89.
[133] Martinez, 30.
[134] Camp, 89.
[135] Ibid, 89.
[136] Jasper et al, 121.
[137] Richardson, 23.
[138] Camp, 89-92.

recalls that the only remaining identifiable item on many of the men were the soles of their shoes. Only one man, Corporal Burnis Leroy Bond, made it out of casemate ten, only to die before he could be evacuated.[139]

Those who were able to make it off the ship still had a difficult and perilous journey before them. Some found their way back to Ford Island by way of motorboats manned by those who had already made it off the burning ships. Others were forced to swim back to shore while facing debilitating injuries sustained during the attack. Adding to the intensity of this journey was the oil burning on the surface of the water. Ironically though, the one saving grace found on the water for some was an oil pipeline standing about a foot out of the water (see image 7). Many used this to help to pull themselves through the water toward Ford Island.[140]

Although the accounts differ regarding the amount and type of attack that the USS *Arizona* endured, the most likely scenario included four bomb hits. The first hit was near frame 85 on the port side. The second was also on the port side, near frame 96. A third bomb, as mentioned, ricocheted off the No. 4 turret and detonated in the Captain's Pantry. The final and most devastating of the bombs hit on the forward starboard side of the No. 2 turret.[141] The USS *Arizona* was home to 1,514 men at the time of the attack. After the smoke had cleared, 1,177 of these men had lost their lives. This equates to a 78 percent death rate on the USS *Arizona*. Nearly half of the total Navy and Marine fatalities from the Pearl Harbor attack came from this single ship.[142]

From Sunday the 7th to Wednesday the 10th, the ship continued to burn. Even days after the fire was quelled, the sections of the deck that remained above the waterline were too hot to

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[139] Ibid, 89,96.
[140] Ibid, 96-101.
[141] Stillwell, 274.
[142] Ibid, 255.

walk on. This kept salvage and body retrieval crews off for approximately a week. When they were able to access both the topside and underwater sections of the ship, the crews working to remove the bodies were in many cases, made up of the survivors. Efforts to remove human remains were short-lived however, because soon afterward the conclusion was reached that not enough of the bodies could be identified to continue. Approximately 900 bodies remained on the ship after the salvage.[143]

In the year following the attack, salvage crews began work in Pearl Harbor. Salvage was conducted first on the ships that could be repaired sufficiently to be placed back into service. The USS *Arizona* was determined, for obvious reasons, to be mainly unsalvageable, though there were sections that were removed from the superstructure.[144] These included the ship's fore and main masts, stern aircraft crane, the conning tower, all anti-aircraft guns including the 5-inch/51 caliber, and 5-inch/25 caliber guns, the after turrets with their guns and ammunition, and what remained of turret two (see image 8). The crews removing these items worked from a berth placed abreast of the ship's remains (see image 9).[145] Most of the items taken during this period were scrapped, although the two salvaged after turrets were slated for recycling as part of an island defense system. The two turrets were divided up between the Pennsylvania and Arizona Batteries, located on the Northern shore of the island. Construction was slow going at best; the Pennsylvania Battery was not completed until 1944. While the Navy did organize the installation of motors at the Arizona Battery, the defense system there was never completed and

[143] Stillwell, 225-259.
[144] *Salvage Operations on USS ARIZONA, USS OKLAHOMA and USS UTAH-Decision as to Extent of*, March 15, 1943; Navy Bureau of Ships General Correspondence 1940-1945, Record Group 19, Box 129, Entry 1265; National Archives Building, Washington, DC.; C.W. Nimitz, *Salvage Operations on U.S.S. ARIZONA, U.S.S. OKLAHOMA and U.S.S. UTAH- Decision as to Extent of,* March 24, 1942; Serial # 0933, File # S94/(50), Navy Bureau of Ships General Correspondence 1940-1945, Record Group 19, Box 129, Entry 1265; National Archives Building, Washington, DC.
[145] William R. Furlong, *Salvage Operations on USS ARIZONA-Recommendations Regarding*; Serial # Y-01348, Navy Bureau of Ships General Correspondence 1940-1945, Record Group 19, Box 129, Entry 1265; National Archives Building, Washington, DC.

both the salvaged turrets and guns of the USS *Arizona* were scrapped, leaving only concrete holes where the Batteries resided.[146]

The site of the USS *Arizona* wreckage was essentially left to rot until March 7th 1950, when the Commander of the Pacific Fleet, Admiral Arthur W. Radford, oversaw the erection of a flagpole on the site. This was the first maintained memorial, as the flag had to be raised and lowered each day. Eight years later, a bill was passed to allow the Navy to receive funds from the Pacific War Memorial Commissions to build a memorial for the USS *Arizona.* In addition to the money provided by the commission, multiple fundraisers were held. The most notable of these was Elvis Presley's Pearl Harbor concert in 1961, which contributed $65,000 to the cause. The total cost of the memorial, less the visitor's center (built 18 years later), was $500,000, and it took two years to build (see image 10).[147]

Although the ship that lies in the deep mud of Pearl Harbor only spent a few short moments under attack, it shall forever be remembered for the monumental number of lives lost on December 7, 1941. The men who shall spend eternity in the remains of the USS *Arizona* were, in many cases, the same who had traveled with her throughout the Atlantic and Pacific. The information presented within this chapter shows that the vessel currently lying in Pearl Harbor differs in many ways from the one that was built in the New York Shipyard in 1914. By exploring the original construction of the ship, the technical improvements, and the attack and subsequent salvage, a better understanding of the *Arizona* can be achieved. The next chapter will include information pertaining to the current state of the wreck and the possible effects of the vessel on the surrounding environment

[146] Stillwell, 278-281; R.W. Paine, *U.S.S. ARIZONA-Turrets 3 and 4 – Mounted on Shore – Motors for*, June 3, 1943; Serial Y – 01127, Navy Bureau of Ships General Correspondence 1940-1945, Record Group 19, Box 129, Entry 1265; National Archives Building, Washington, DC.
[147] Stillwell, 281-286.

Chapter 2: The Current State of the USS *Arizona*

The wreckage that lies in the mud of Pearl Harbor does not represent the same ship originally built twenty-seven years prior to its sinking. Because of significant technical improvements to the USS *Arizona'*s hull and superstructure, the ship that sank on December 7, 1941 was much more heavily built than the original vessel. Therefore, making an informed decision about the removal or remediation of the ship's oil will first require a detailed analysis of the current hull condition and specifications. Included in this chapter is the hull's present condition, along with all of the collected corrosion and environmental data obtained from various studies. Other well-documented case studies regarding corrosion and underwater defueling will then be compared to the information regarding the USS *Arizona*. Combined, this will help to answer the following questions that form the basis of this thesis: is the USS *Arizona* in danger of imminent structural failure, and, what is the likely effect of hull deterioration to the surrounding environment?

Seventy years after the attack on Pearl Harbor, problems are continuing to occur at the site. In 1984, a visual study was conducted by the National Park Service to determine the hull's condition. This research is the basis for the current artistic representations of the ship. (see image 11).[148]

Starting at the bow and moving aft, a diver at the site would see little damage until around frame 10, which is approximately 40 feet aft of the bow. Here, weather and forecastle decks are still present, as are portions of low-relief superstructure, such as deck fittings and fairleads. Moving aft of frame 10, the damage quickly becomes apparent, in the form of jagged

[148] Lenihan ed., 81-95

and splayed metal. Here, the deck elements previously seen in the undamaged area are generally indistinguishable from the blown apart decks and debris.[149]

The No. 1 turret gunhouse and 14-inch gun tubes remain, although the structure sits 15 feet lower than it would have prior to December 7 because of the collapse of the No. 2 bulkhead below it. Surrounding the turret are remnants of teak decking and the forecastle deck. The general lack of identifiable remains here is a direct result of the damage the ship sustained during the attack. Despite this, there is also evidence of post-sinking human activity. On the port side, near the No. 1 turret, an access hatch remains open that was likely opened by salvage divers directly after the sinking. Other than some hatch combings, very little of the main or forecastle decks remains in the blast zone. This is mainly due to naval salvage efforts.[150]

Thirty feet aft of the beginning of the blast site at turret two, the torpedo blisters bulge from the starboard and port sides, and apparent evidence of the work of naval divers can be seen. Due to this, a majority of the side armor, from the torpedo blister to the gunnel, is missing. Documentation confirms that significant salvage activity occurred in this area because of dangerous metal overhanging the port side. The kerf marks from the diver's torches are apparent, and help to differentiate the sections that were cut away, from those damaged by the blast.[151]

Damage continues past the primary blast site, although significantly less than in the previous area. At two points, approximately 80 and 112 feet (24.38 and 34.14 meters) aft of the bow, two large cracks present themselves, and continue through the torpedo blister into the mud line. According to Daniel Lenihan and Larry Murphy, these cracks likely represent major structural damage received during the Pearl Harbor attack, and subsequent sinking of the USS

[149] Ibid.
[150] Ibid.
[151] Ibid, 81-82.

Arizona. These researchers also believe that the cracks extend into the armor belt and interior hull structures.[152]

Midships, forward of the stack, the boat deck is missing due to salvage efforts. This allows for visual identification of artifacts such as medicine cabinets, brackets, gaskets, and electrical fittings. Continuing aft, the galley quickly becomes apparent. This is another area of significant associated artifacts such as table legs, oven bottoms, the original tile flooring, and doorways. Some items in this area though did not originate on the ship. Deposited items such as leis and coins, and less intentional items such as sunglasses and cameras, can often be found in this area.[153]

Moving underneath the present-day memorial, the ship is generally intact, with port 5-inch gun barbettes still visible. The majority of the damage seen aft of the monument is the result of salvage. The teak decking previously surrounding the No. 3 turret has been removed, though mooring bitts remain. Much like other areas of the ship previously described, multiple open ports, now encrusted with marine life, are found here. Looking through the ports, one can see that a significant amount of silt is present within the ship.[154]

Continuing aft, a bundled cable of unknown use runs along each of the gunnels. Although the cable was likely for degaussing the ship, this supposition is unconfirmed. Also visible on the stern is the airplane catapult, and a large hole that extends into midships. Opposite this hole, on the port side, are multiple portholes, many of which still have air trapped between the blackout covers and the glass. The final evidence of battle damage is a small hole at the

[152] Ibid, 82.
[153] Ibid, 95-96; Rodgers, Personal Communication.
[154] Ibid, 96.

starboard side of the fantail. Here, the screw propellers are likely still present, although not visually apparent because of significant sediment infilling.[155]

Similar to the visual study conducted years before, the USS *Arizona* Preservation Project, which began in 1998, was created as an interdisciplinary study of the deterioration and factors of corrosion for this historic ship. The majority of the studies included within this project focus on the continuing corrosion of the hull, and the possibility of a catastrophic release of oil.[156]

As a part of the USS *Arizona* Preservation Project, in 2001, GPS datum points were placed on multiple areas of the ship, and labeled as superpoints 1-8. Each of these superpoints was marked with a stainless steel bolt driven into the decking of the *Arizona.* PVC pipes replaced these bolts in 2003 after they were found to have nearly disintegrated. This caused minor precision problems, as the PVC points could not be placed directly on top of the remains of the stainless steel bolts, and were instead installed adjacent (see image 12). The movement of the ship's internal structures was monitored every few years by divers who would descend to obtain new GPS coordinates. This is done by placing a tripod directly over a datum, which holds the GPS antennae out of the water. The instrument height (HI) is then calculated prior to the data point being obtained. In 2006, the datums were recorded using this methodology. Comparison of the 2003 results to the 2006 results established that the ship has made no discernible movement, and that the sediment holding the ship in place is stable and thoroughly compacted.[157]

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[155] Ibid, 96-97.
[156] Russell and Murphy, "Long-Term Monitoring", 388., Matthew A. Russell and Larry E. Murphy, "Research Design," in *Long Term Management Strategies for USS Arizona, A Submerged Cultural Resource in Pearl Harbor* (Santa Fe, NM: Submerged Resources Center, 2008), 22-23, http://www.history.navy.mil/branches/UA_ManagementUSS%20Arizona-a.pdf.
[157] Russell and Murphy, "Long-Term Monitoring", 392-399.

After 70 years underwater, the ship has settled into 25 feet (7.62 meters) of mud. This positioning is slowing the ship's yearly decomposition rate on the port side from 0.087 mm (0.00343 inches) at 19.5 feet (5.94 meters), to 0.027 mm (0.00108 inches) under the mud line at 26 feet (7.92 meters). Corrosion rates above the mud line are variable though. In general, deeper samples have lower corrosion rates, with the highest rate seen only 5 feet (1.52 meters) below the surface of the water on the port side. At the time of the study, the originally half-inch thick plates here had been reduced to approximately 0.135 inches (3.43 mm), equivalent to a 73 percent loss of steel thickness. At 19.5 feet (5.94 meters) below the surface, however, the corrosion rates are significantly slower. The original steel thickness here was 0.88 inches (22.2 mm), but when this area was tested in 2002, the thickness had only decreased by approximately 24 percent, for a hull thickness of 0.67 inches (17.04 mm). [158]

Starboard side corrosion rates above the mud line were slower than those found on the port side because of the increased water movement on the port, caused by boat traffic and natural water flow. At 5 feet (1.52 meters) below the surface the corrosion rate on the starboard side is 0.127 mm (0.005 inches) resulting in a 2002 loss of .304 inches (7.72 mm) or 61 percent. Much like the lowered corrosion rates at 19.5 feet (5.94 meters), at 15 feet below the surface on the starboard side the deterioration slows. Here the corrosion rate is 0.035 mm (0.00139 inches). This equates to a 10 percent loss of 0.085 inches (2.16 mm) in the year 2002.[159]

Both the starboard and port side corrosion rates were acquired from four inch coupons cut from the hull using a hydraulic hole saw. Careful precautions were taken to avoid oil-containing compartments. After the samples were removed, seven of the holes were plugged

[158] Johnson et al., USS Arizona Pt.1, 2-4.
[159] Don Johnson et al., "Steel-Hull Corrosion Analysis of USS Arizona," in *Long-Term Management Strategies for USS Arizona, A Submerged Cultural Resource in Pearl Harbor* (Santa Fe: National Park Service Submerged Cultural Resources, 2008), 219.

with marine epoxy, while one hole was fitted with a removable plug to allow for water sampling in the future.[160]

The pH of the water surrounding the ship is another factor that could indicate the amount of corrosion occurring on the USS *Arizona*. Normal seawater pH ranges from 7.5-8.2 but in areas of active corrosion, this number can decrease to below 6.5.[161] Surrounding the *Arizona,* the water was found to have a pH of between 7.6 and 9.1, with a mean of one standard deviation 8.04 ± 0.15. This means that the water around the wreck is basic, which explains a lessened rate of corrosion.[162] The pH of the water inside the *Arizona* was found to be in a similar range to that surrounding the wreck. The interior of the wreck displayed varying pH levels depending on the area of the wreck being tested. Inside the second deck, the levels ranged from 7.05-9.36 with a 7.69 average, while the third deck had an average of 8.01 and varied from 7.9-8.07. The final area investigated was the No. 3 barbette near the first platform level. This area had the highest average pH, ranging from 8.18-9.36 with an 8.41 average.[163] The pH levels found on the ship correspond to the results found when the hull plates were investigated for corrosion. According to the corrosion study, the highest rates of corrosion were found closest to the surface.[164] The second deck was the area tested that was closest to the surface, and where the pH was found to be the lowest. Despite this, the relatively high pH levels throughout the ship show low corrosion rates.

While collection of current corrosion data is essential, the ability to extrapolate this information into the future is also necessary in a potentially hazardous situation such as that

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[160] Johnson et al., USS Arizona Pt.1, 2-4.
[161] N.A. North and I.D. MacLeod, "Corrosion of Metals," in *Conservation of Marine Archaeological Objects*, ed. Colin Pearson (London: Butterworth &, 1987), 74.
[162] Curt Storlazzi et al., "Dynamics of the Physical Environment on the USS Arizona," in *Long-Term Management Strategies for USS Arizona, A Submerged Cultural Resource in Pearl Harbor*, ed. Larry Murphy and Matthew Russell (Santa Fe: Submerged Cultural Resources Center, 2008), 106.
[163] Ibid, 116.
[164] Johnson et al., USS Arizona Pt.1, 2-4.

presented by the USS *Arizona*. To do this, a Finite Element Analysis (FEA) model was created, which mapped the stresses accrued since the sinking event. This process works by creating, "a computer-manipulated mathematical model that calculates theoretical stresses and shape changes in a structure under load using experimental variables based on observationally-derived data."[165]

When working with FEA, as with any modeling system, the inclusion of more detail makes the model significantly more accurate. For this reason, the FEA team decided to model only from frames 70-90—an 80-foot expanse in total (see image 13). This section of the ship is aft of the main blast site, and was chosen because it was the forward-most section of the ship that was likely to have oil remaining within the bunkers, as well as areas affected by the explosion and subsequent burning. According to the modeling team, this area provides a worst case scenario due to its proximity to the explosion, which had negatively affected the stability of the hull.[166]

After imputing the ship's original pre-sinking stresses, the team extrapolated the data to the approximate years 1980, 2020, 2050, 2120, 2150, 2180, and 2240. At each of these dates, the stresses accrued by the ship were confirmed to increase. According to the 2020 model, at this point in the future, the deck plate and beams begin to sag, while the steel at the turn of the bilge is reaching its tensile strength. Although their corrosion analysis data shows this occurring around the year 2020, this was actually the state of the ship as of 2009. This means, at least in this one case, that the ship is deteriorating at a rate 11 years faster than the model predicts.[167]

The final model in this set was the year 2240. According to the researchers, by this date, 90 percent of the hull structure will have been lost to corrosion. The superstructure decks, which have been slowly deteriorating up to this point, will collapse and fall into the third deck. The

[165] Foecke et al., 3.
[166] Ibid, 3-4.
[167] Ibid, 8-10.

double bottom will also have buckled. According to Foecke et al., however, the inner oil tanks holding the majority of the remaining fuel are, at this date in the future, still relatively intact.[168]

The data presented in the FEA model was painstakingly researched and detailed in many ways, though a potentially devastating problem still may lurk. The researchers decided, because of the scale used, that fasteners would be too small to take into account. Because of this, no rivets were included and the section was instead modeled as a single piece of steel stretching the entire 80 foot (24.38 meter) section from frames 70-90. This assumption could significantly affect the model because it ignores the possibility of the hull plates separating in areas of high stress due to the deterioration of the corroded rivets. [169]

Steel wrecks have shown in multiple cases that among the first points to corrode are the rivets. While investigating the *Titanic*, researchers found that the rivets and other fasteners displayed the highest levels of corrosion on the ship because these are areas of great mechanical stress.[170] In addition to this, visual inspection of the 387-foot passenger liner S.S. *Mohawk,* which sank on January 25, 1935 in the waters off of New Jersey, showed significant deterioration of the rivets. In many cases, the rivets had actually completely disintegrated (see image 14).[171]

During a metallurgy study, samples of rivets and hull plating were taken both directly from the hull of the USS *Arizona*, and from the salvage remains that had been left in the water at Waipio Point. The hull and rivet samples were studied to determine the rate at which corrosion was penetrating the steel. While, on average, the three hull samples are corroding at a rate of

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[168] Ibid, 10.
[169] Ibid, 4.
[170] Sarah Don, "Titanic-Resting or Reacting," Scribd, 2008, accessed June 22, 2011, http://www.scribd.com/doc/11337904/Titanic-Resting-or-Reacting.
[171] Rich Galiano, "Scuba Diving - New Jersey & Long Island New York - Dive Wreck Valley - Dive Sites - S.S. Mohawk Shipwreck," Scuba Diving - New Jersey & Long Island New York - Wreck Valley, 2008, Getting Around on the Mohawk, accessed June 23, 2011, http://njscuba.net/sites/site_mohawk.html

3.83 thousands of an inch, or mils per year (mpy) (0.097 mm), the heads of the rivets in the sample were corroding at a much higher rate. These were found to be corroding at a rate of 5.3 mpy (0.13 mm), resulting in an approximate total corrosion penetration of 271 mils (6.887 mm) in the 70 years since the sinking (see image 15).[172] This deterioration is likely because of the riveting process used during the construction of the ship. Rivets would be heated to red hot before being hammered into place, and quickly cooled. This method caused significant deformation to the rivet heads, as well as decarburization, a process resulting from the heating of the rivets, which diffused carbon onto the surface of the metal, allowing it to corrode more quickly, and creating a layer of ferrite.[173] Because of the increased level of corrosion occurring at the heads of the rivets, it is beneficial to include these in any model representing the corrosion rate of the USS *Arizona.*

Hull failure at the USS *Arizona* site is an inevitability. Because of this, the problems potentially surrounding a catastrophic hull failure must be acknowledged. As mentioned in the introduction, continual monitoring stations have not been used since 1988 because of financial constraints.[174] This forces the use of case studies to supplement the available data sources.

To understand spills like that originating from the USS *Arizona*, the oil itself must be studied. The 4,630 tons of oil carried within the USS *Arizona* at the time of the sinking is classified as Bunker C, also known as No. 6 oil. Number 6 fuel is the residual oil left from the number 6 heavy petroleum distillation-boiling fraction process, which extracts distillate fuels and gasoline from the oil. [175] Because of this, No. 6 oil is designated as a residual fuel oil (RFO).[176]

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[172] Nathan Saunders and Elliot Hamilton, "Metallurgical and Corrosion Analysis of the U.S.S. Arizona," 2009, Corrosion Rate Analysis, accessed August 6, 2011, http://snr.unl.edu/gpcesu/PDFs/USS%20Arizona.pdf.
[173] Saunders and Hamilton, Metallurgical Analysis. Corrosion Rate Analysis.
[174] Russell and Murphy, "Long-Term Monitoring Program", 421.
[175] Graham, 297-299; Rick Wallace, "Definitions of EIA Distillate Categories and Fuels Contained in the Distillate Grouping," Department of Environmental Quality, No. 5 fuel oil and No. 6 fuel oil, accessed July 14, 2011, http://www.deq.state.or.us/aq/committees/docs/lcfs/definitions.pdf.

This particular fuel contains higher levels of heavy carbon molecules, a density of 971 kg/m^3 at 20°C, and has a low-water soluble fraction (WSF) of <10 ppm. This makes the oil itself difficult to work with because of its thickness and resistance to evaporation.[177] Heavy carbon molecules also make the oil viscous, so it must be heated or combined with lighter fuels for use.[178] After a spill of Bunker C oil, only 10 percent of the oil will evaporate, compared to a 75 percent evaporation rate for lighter fuels.[179]

The polycyclic aromatic hydrocarbon (PAH) level in oils, such as that contained within the USS *Arizona*, helps to make the substance more biodegradable. High levels of PAH allow the oil to undergo a weathering process called photo-oxidation. After this process has occurred, the oil will be slightly broken down and more susceptible to dissolution in water than its crude oil counterparts. While this process can be beneficial, it also allows the oil to reach the sediment below, where it can become tightly embedded and potentially very difficult to clean.[180]

While the oil does become more water-soluble, the majority remains on the surface. This is due to the heavier molecules impeding much of the oil from entering the water column. Because of this, the greatest danger from a spill of this type is the possibility of ingestion of oil by organisms living within or on top of the water. [181] Nearly every part of a contaminated marine animal can be affected in a number of different ways. This includes, but is not limited to, the blood, eyes, skin, liver and mouth. Possibly most devastatingly, the reproductive capabilities of the animal can be damaged, thereby affecting future generations.[182]

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[176] Wallace, “Definitions of EIA”.
[177] Graham, 297-299.
[178] Rodgers, Personal Communication.
[179] Graham, 297-299.
[180] Ibid, 298.
[181] Ibid, 299.
[182] "Effects of Oil on Wildlife," Australian Maritime Safety Authority, accessed July 11, 2011, http://www.amsa.gov.au/marine_environment_protection/educational_resources_and_information/teachers/the_effects_of_oil_on_wildlife.asp.

In 1999, the *Erika* sank thirty miles off the coast of France. The effect of this sinking was a 20,000 ton spill of heavy fuel oil. Making this spill worse was the winter storm that hit directly after the initial sinking, dramatically slowing the cleanup efforts. Four hundred kilometers of the French coastline were devastated by the spill, which affected water birds and marine animals alike. Due to the extensive damage, this spill was the most expensive in International Oil Pollution Compensation Funds history. The amount of oil contamination in the water led to a ban on bivalve fishing and farming until 2001.[183] By far, however, the most affected animal was a marine bird, *Uria aalge*, also known as the common guillemot.[184] Between 64,000 and 125,000 of these birds died within the first month of cleanup. Approximately one-third of these birds were less than one year old.[185] This highlights the importance of a swift response to a spill of this nature.

When cleanup efforts are quickly initiated for Bunker C oil spills, the results are significantly less detrimental to the environment. This was shown following the 1988 sinking of the *Nestucca*. The 230,000 gallon (870,644.71 liter) spill associated with the wreck was cleaned with oil absorbing pads and pom-poms. Two years later, when the surrounding coastline was examined, only small amounts of the oil remained.[186] This is similar to what might occur if the USS *Arizona* was to fail catastrophically. The oil would likely be cleaned quickly because it is such a high profile wreck.

The sinking and emulsification of oil generally results from areas of high wave and tidal action because of the water based agitation in these areas. Unemulsified No. 6 fuel oil has a

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[183] Nadia Kamm, "An Overview of Pollution from Shipwrecks" (diss.), Oil, accessed June 25, 2011, http://lawspace.law.uct.ac.za/dspace/bitstream/2165/353/1/KMMNAD001.pdf.
[184] "Common Murre," Wikipedia, the Free Encyclopedia, accessed June 27, 2011, http://en.wikipedia.org/wiki/Common_Murre.; Kamm, "An Overview of Pollution", Oil.
[185] Kamm, "An Overview of Pollution", Oil.
[186] Graham, 302.

specific gravity of 0.95-1.03, while seawater's specific gravity is 1.025.[187] This means, typically, that this type of fuel oil floats on top of the water, although, because the specific gravities are similar, some of the oil could possibly begin to mix with the water column. Emulsification continually increases the water content percentage, thus bringing the specific gravities even closer and promoting mixing.[188] This, however, is not currently the case at the USS *Arizona* site. Between 2000 and 2001, researchers sampled sediment surrounding the wreckage to determine the effects of the oil. The results showed that the oil was causing a negligible amount of damage during the test period. On average, the samples showed 1.79 mg extractable material/g dry sediment. This value was lower than the values for samples taken at other oil-contaminated sites, which ranged from 1.91-84.08 mg extractable material/g dry sediment.[189] The low numbers seen at Pearl Harbor are most likely due to the previously mentioned PAH levels, and the generally low wave action seen within the protected fan-shaped harbor.[190]

The microbial presence around the USS *Arizona* is such that some of the leaking oil is being degraded. Aerobic enrichment cultures were taken from the harbor's sediment and inoculated with the oil leaking from the ship. After 30 days, a sample of the oil taken from the ship had degraded 31.03 ± 4.58 percent. This was significantly higher than the degradation occurring in an uninoculated control sample, which only had a loss of 6.13 ± 0.65 percent. This

[187] "No. 6 Fuel Oil (Bunker C) Spills," National Oceanic and Atmospheric Administration, November 2006, Characteristics of No. 6 Fuel Oil (Bunker C) Spills, accessed July 23, 2011, http://response.restoration.noaa.gov/book_shelf/971_no_6.pdf.; "Specific Gravity- Liquids," The Engineering Toolbox, accessed July 23, 2011, http://www.engineeringtoolbox.com/specific-gravity-liquids-d_336.html.
[188] Cormack, 74-83.
[189] Graham, 372.
[190] "Pearl Harbor and Honolulu Harbor Hurricane Haven Study (U) UNCLASSIFIED," Naval Research Laboratory Monterey, Pearl Harbor, accessed July 23, 2011, http://www.nrlmry.navy.mil/~cannon/thh-nc/hawaii/text/sect4.htm.; Cormack, 83.

shows that the oil emanating from the wreckage is being partially degraded by the microbial activity surrounding the ship.[191]

The low rates of oil sedimentation that are seen surrounding the USS *Arizona* coincide with data taken from the ship's leakage rates (see figure 1). In 1998, efforts were initiated to determine the amount of oil emerging from the wreckage by collecting it from a single release site. To complete this, a tent was constructed to collect the oil for a predetermined length of time. The oil recovered from the tent was then measured, and a 24-hour release rate calculated. In 2003, the number of oil release sites measured was increased to two, and then increased again in 2006 to eight. When values from all eight sites were combined, the ship was found to be leaking approximately 9 liters (9.5q) per day.[192]

The leakage points throughout the ship were also tested for weathering. The results of this showed that all leakage points except for those surrounding barbette #4 showed a decrease in n-alkanes, a result of weathering from the oil being exposed to seawater for 30 days or more. The oil resulting from near barbette #4, designated in Figure 5 by the aft most circle, and in Figure 2 by "Location A", however, did not have depleted n-alkanes, and thus was likely originating from an original oil containment space. A small decrease has been seen in this leak as a whole over the years though, hopefully indicating the oil leaking from the ship as a whole is mainly originating in secondary oil locations.[193]

While current quantitative studies that specifically focus on the USS *Arizona*'s oil may be somewhat limited, vast amounts of qualitative evidence can be gained from photographs taken of the site, and from personal experiences. Those who visit the *Arizona* invariably notice, and in many cases document, the oil emanating from the ship. Despite this, to determine the possible

[191] Graham, 374-375.
[192] Russell and Murphy, "Long-Term Monitoring", 408-466.
[193] Ibid, 406-408.

future problems that the wreck could endure, case studies of similar situations must be combined with the qualitative and quantitative evidence specifically associated with the USS *Arizona.*

CASE STUDIES

While the USS *Arizona'*s oil leakage is high profile because of its historical importance, it is only one of many thousands of ships throughout the world that are leaking oil. In 2010, this very issue took the forefront with the *Deepwater Horizon* disaster. The explosion occurring on April 20, 2010, created a spill releasing 35,000-60,000 barrels of oil per day from the ocean floor.[194] Since each barrel is equivalent to 42 US gallons, this calculates to between 1,470,000 and 2,520,000 gallons (5,564,555.32 and 9,539,237.7 liters) per day, vastly more than what is assumed to be contained within the entire *Arizona* wreck.[195] Because of the far-reaching and devastating effects of this spill, the environmental impacts of oil have come to the attention of many Americans. The following oil spill and defueling data were derived from case studies selected because of their circumstantial similarities to the USS *Arizona.*

The first case study included here is the defueling of the *Princess Kathleen.* The information from this shipwreck is comparable to that of the USS *Arizona* because, when the *Princess Kathleen* sank, not only was this ship carrying the same type of Bunker C oil, the ship has been underwater a similar amount of time. Because of this, the theory behind some of the techniques used during the defueling process could be applied to the USS *Arizona.*[196]

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[194] "U.S. Scientific Team Draws on New Data, Multiple Scientific Methodologies to Reach Updated Estimate of Oil Flows from BP's Well," Deepwater Horizon Response, Accessed August 24, 2010. http://www.deepwaterhorizonresponse.com/go/doc/2931/661583/.
[195] "How Many Gallons are in a Barrel of Oil," Answers.com, Accessed August 24, 2010, http://wiki.answers.com/Q/How_many_gallons_are_in_a_barrel_of_oil&alreadyAsked=1&rtitle=How_many_gallons_in_a_barrel_of_oil.; Rodgers,7.
[196] Christopher Philips, ed., "Princess Kathleen Comes Clean," *Pacific Maritime Magazine* 28, no. 10 (October 2010): 42.

The *Royal Oak* is another case that is very similar to the USS *Arizona.* Much like the *Arizona,* this British warship is a military tomb originally containing over a thousand tons of oil. This wreck, however, was leaking significantly more than the *Arizona.*[197] While this is not the current situation of the historic Pearl Harbor shipwreck, it is important to use this case study as a warning of what could occur in the future, and how to mitigate public opinion.

While the corrosion data for the USS *Arizona* concludes that the ship is relatively stable, situations may arise that cannot be accounted for.[198] The most dangerous of these unpredictable elements is likely a storm. The USS *Mississinewa,* which sank in the Ulithi Atoll in Micronesia, began significantly leaking oil after a particularly bad storm in 2001.[199] Pearl Harbor could experience a similar storm, which would potentially affect the current stability of the hull. By studying the USS *Mississinewa* case, a better understanding of this possible situation could be obtained.

PRINCESS KATHLEEN

June 11, 2010 marked the final day of work on the *Princess Kathleen* site for Global Diving and Salvage, the company chosen to defuel this potentially hazardous ship.[200] While this marked what would likely be one of the final significant dates in the history of this ship, its story had begun years before. The *Princess Kathleen* was built in 1924 by the Scotland-based John Brown & Company, and was operated by the Canadian Pacific Railroad BC Coast Steamships. When built, she was 5,875 tons, 369 feet in length, and 60 feet in beam. The majority of the vessel's lifetime was spent serving as a luxury passenger ship on the British Columbian and

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[197] Jacqueline Michel et al., "Potentially Polluting Wrecks in Marine Waters," proceedings of International Oil Spill Conference, 2005, accessed June 23, 2011, http://www.iosc.org/docs/IOSC_Issue_2005.pdf.
[198] Foecke, 10.
[199] U.S. Navy, *U.S. Navy Salvage Report USS Mississinewa Oil Removal Operations,* report no. S0300-B6-RPT-010, May 2004, Introduction and Background, accessed June 25, 2011, http://www.essmnavy.net/Mississinewa%20Oil%20Removal%20Operations.pdf.
[200] Global Diving and Salvage, *Situation Report: As of 10:00am June 11, 2010*, report no. 26, 1, accessed May 26, 2010, http://www.dec.state.ak.us/spar/perp/response/sum_fy10/100216101/100216101_sr_26.pdf.

Southeast Alaskan Coasts. Despite this, the ship briefly served as a troop transport during World War II.[201] On September 7th, 1952 the *Princess Kathleen* was steaming near Juneau.[202] Although the ship did have radar, this was turned off at the time because the captain believed it was unnecessary. He was mistaken, however, because the ship crashed into the rocks early that morning. It was three and a half hours before assistance would arrive to help the 307 passengers and 80 crew members off the stranded ship (see image 16).[203] Upon inspection, a tear was found in the hull that extended from the bottom to nearly midships.[204] As the tide rose, it picked the ship up and slowly pulled it off the rocks, to where it still lies today.[205]

When divers working for Global Diving and Salvage descended on the wreck of the *Princess Kathleen,* they found it lying on the port side at an 80° list. The ship had settled 134 feet below the surface at the stern and 52 feet below at the bow. The *Princess Kathleen*, which had lain on the bottom for nearly fifty years, had become a popular local diving spot. However, as the sheening from the leaking oil became more prominent, the Coast Guard and the Alaska Department of Environmental Conservation decided that the ship had to be defueled. The ship was estimated to contain approximately 155,000 gallons of Bunker C fuel.[206]

When the defueling project for the *Princess Kathleen* began, the first step was to clean the hull so that the ship could be examined. Using what the dive teams referred to as "barney busters," the hull was methodically revealed. This process allowed ultrasonic thickness readings, which returned surprising results. Much of the steel hull plating tested was still close to or

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[201] Nathan Menefee, "The Sinking of the Princess Kathleen | The Maritime," The Maritime Blog, March 2, 2010, accessed May 26, 2011, http://themaritimeblog.com/1718/the-sinking-of-the-princess-kathleen.
[202] Philips, "Princess Kathleen", 42.
[203] Ibid.
[204] "The Wreck of the Princess Kathleen," *Life*, September 22, 1952, 27, accessed July 14, 2011, http://books.google.com/books?id=AFYEAAAAMBAJ&pg=PA27&source=gbs_toc_r&cad=2#v=onepage&q&f=false.
[205] Menefee, "The Sinking of the Princess Kathleen".
[206] Philips, "Princess Kathleen", 42.

within the ship's original specifications. The rivets, on the other hand, were significantly deteriorated. According to project manager Kerry Walsh, if the divers mistakenly hit one of the rivets with the barney buster, it would crumble. This added logistical problems during pumping because positive pressure could burst the rivets and breech the ship's oil tanks.[207]

During the original assessment, small holes were drilled into the tanks to determine the fuel-oil levels. This survey showed that the cold water temperatures had stratified the oil, and the different components had separated to the top and bottom of the tank (see image 17). This was problematic because the heavier components had settled to the bottom, creating an asphalt-type sludge.[208] Global Diving and Salvage bypassed this, and the problem of the oil's thickness, by using a hot-tap (see image 18). To perform this process, half-inch threaded holes were drilled into the hull of the ship and covered by a landing plate which had a flange and pipe welded to it. The four half-inch holes in the landing plate were lined up with the previously threaded ones, and used to bolt the plate to the hull (see image 19). A valve was then attached to the pipe before the hot-tapping tool was secured to the flange. The hot-tap extended a saw that bored a 4-inch hole through the hull before retracting back. Once the valve was closed, the oil would not pour out, and the saw could be removed. This had to be done three times for every tank. The first hole was for the fuel extraction, the second for the recirculation of hot water, and the final provided a vent for the process.[209]

Once the holes were drilled into the oil tank, the defueling process began. To do this, a pump was attached to the extraction hole, removing the oil to a portable 20,000 gallon (75,708.24 liter) tank on the surface. This tank was half filled with water that had been intensely heated with a steam boiler. The heated water was then recirculated back into the fuel tank so that

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207 "Interview with Kerry Walsh," telephone interview by author, February 12, 2010.
208 Philips, "Princess Kathleen".
209 "Interview".

the amount of oil being removed was continually equal to the amount of water replacing it. Once oil stopped emerging from the pumpline, the process was moved to the next tank.[210]

Both the USS *Arizona* and the *Princess Kathleen* were filled with Bunker C oil. Because the water temperature in Hawaii is warmer than Alaska, the process of hot-tapping used on the *Princess Kathleen* would likely need to be modified to exclude the water heating if defueling was deemed necessary. Despite this, the defueling method would be likely very similar to the hot-tapping process. In addition, as previously mentioned, the heads of the rivets on the USS *Arizona* are corroding at a rate of 5.3 mpy (.13mm).[211] Because of this, they are likely similar to the brittle rivets found on the *Princess Kathleen.*[212]

When the *Princess Kathleen* settled on the bottom, it did so lying on its port side. Although the divers could defuel the starboard side bottom tanks, thick mud made direct access to the port side wing tanks impossible. To solve this problem, Global Diving and Salvage originally proposed digging tunnels through the mud to access the hull, a solution which could potentially destabilize the wreck. Due to fortuitous events, blueprints from 1947 were found, which guided divers through the ship's interior. After the silt was dredged out, the interior hatches could be opened and the oil was removed.[213]

As it lies today in Pearl Harbor, the USS *Arizona* is sitting in approximately 25 feet (7.62 meters) of mud. The tanks currently containing oil are buried beneath the mud line and are located as follows: 30 bunkers on the first platform, which is located below the third deck, 34 bunkers on the second platform, 28 bunkers in the hold, and 36 bunkers in the double bottom (see image 20). Each of these bunkers is individually piped, which means that to remove the oil,

[210] "Interview".
[211] Saunders and Hamilton, Corrosion Rate Analysis.
[212] "Interview".
[213] Ibid.

each of the tanks would need to be tapped independently.[214] This makes the defueling of the battleship much more difficult than that of the *Princess Kathleen*. Although blueprints exist that possibly indicate passageways to help divers penetrate the wreck and remove the oil internally, there are multiple reasons why this is likely not a realistic solution for the sunken battleship.

A ROV investigation of the USS *Arizona* showed that access to the fuel tanks from inside the ship would necessitate the cutting of multiple internal structures. No specific data are available to indicate how much sediment is contained within the areas of the ship where the ROV could not travel, but, in spaces that could be penetrated, the sediment levels were high. Because of this, much like in the case of the *Princess Kathleen*, significant dredging would have to occur both internally and externally in order to defuel the vessel. In addition to this, vital internal components would need to be reinforced to provide continued structural integrity to the ship.[215]

After the USS *Arizona* sank, short-lived efforts were made to remove the bodies trapped within the ship. In the end, however, approximately 900 bodies remained within the confines of the hull. Since the ship sank, additional remains have been added to the wreck, as some survivors of the *Arizona* disaster wished to be cremated and interred back onto the ship they loved so well. The remains, which continue to reside inside of the USS *Arizona*, make it not only a memorial, but also a war grave.[216] The National Park Service believes that the human remains left on the wreck site have decomposed.[217] This conclusion was reached due to the lack of remains identified by a mini-sub investigation in 2001, which penetrated the interior of the wreck.[218]

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[214] Russell and Murphy, "Long-Term Monitoring", 392.
[215] Ibid, 391.
[216] Johnson et al., 2.
[217] Stillwell, 259.
[218] Dan Nakaso, "Memorial Gets Checkup," *The Honolulu Advertiser*, June 22, 2001., Associated Press, "Mini-Sub Gives First Peek Inside Sunken Arizona," *Las Angeles Times*, June 23, 2001.

However, on April 1, 2011, while Pearl Harbor was being dredged, a skull was found. It is presently being dated to the 1940s. Because of associated artifacts, many believe the remains came from a Japanese pilot who was shot down during the attack on Pearl Harbor. No matter to whom the skull belonged, the fact that it was not deteriorated points toward the possibility of human remains still existing within the USS *Arizona.*[219] Human remains significantly older than those possibly existing on the USS *Arizona* have also been located. In 2006, remains believed to be 10,000 years old were found in a submerged saltwater cave along Mexico's Yucatán Peninsula.[220] In addition to this, a case study involving submerged pig carcasses showed that very little animal based decomposition was seen in areas of low oxygen.[221] Research into the water composition within the USS *Arizona* concluded that the oxygen content in the wreck was lower than that in the surrounding harbor. As the researchers moved deeper in to the recesses of the wreck, the oxygen content continued to decrease. In internal areas of the ship that did not receive active seawater exchange, the dissolved oxygen rate was nearly zero.[222]

As previously mentioned, the pH in the various internal areas of the USS *Arizona* ranged from 7.05-9.36.[223] Very few studies have been conducted on the effects of pH on human remains. Despite this, Angi Christensen and Sarah Meyers investigated further into this very subject. Bovine bones were placed into solutions containing pH levels of 1, 4, 7, 10, and 14, and studied over the course of a year. While the acidic solutions negatively affected the bones fairly

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[219] Jennifer Kelleher, "APNewsBreak: Skull Discovered at Pearl Harbor - Yahoo! News," Yahoo! News - Latest News & Headlines, July 21, 2011, accessed July 25, 2011, http://news.yahoo.com/apnewsbreak-skull-discovered-pearl-harbor-203334414.html.

[220] Ker Than, "Undersea Cave Yields One of Oldest Skeletons in Americas," *National Geographic*, September 14, 2010, pg. #, accessed November 9, 2010, http://news.nationalgeographic.com/news/2010/09/100915-oldest-skeleton-underwater-cave-science/.

[221] Gail Anderson, "Forensic Entomology and the Underwater Death Scene," *Gazette* 72, no. 1 (2010): accessed November 09, 2010, http://www.rcmp-grc.gc.ca/gazette/vol72n1/vol72n1-eng.pdf.

[222] Russell and Murphy, "Long-Term Monitoring", 388., Matthew A. Russell and Larry E. Murphy, "Conclusions and Recommendations," in *Long Term Management Strategies for USS Arizona, A Submerged Cultural Resource in Pearl Harbor* (Santa Fe, NM: Submerged Resources Center, 2008), 456, http://www.history.navy.mil/branches/UA_ManagementUSS%20Arizona-a.pdf.

[223] Storlazzi et al., "Dynamics of the Physical Environment on the USS Arizona", 116.

quickly, the neutral and more basic solutions, up to pH 10, were found to have the highest levels of preservation. In the neutral pH 7 solution, the tissue slowly detached from the bone, and after one year, the bone itself was in good condition with soft adipocere still retained within the marrow areas of the bones. The bones in the pH 10 solution were even better preserved. After one year, some soft tissue still remained within the solution, and hard adipocere was found both on the outer portion of the bone and within the marrow cavity.[224] This study reinforces that the pH of the water surrounding the *Arizona* could support the presence of human remains within the USS *Arizona*.

Regardless of the presence or absence of physical remains, the status of the wreck as a war grave remains unchanged. The public's strong feelings toward the sacredness of the site are not as connected to physical remains, as to the emotions that the Pearl Harbor site evokes. Most believe the USS *Arizona* should not be modified in anyway. Because of this, if the oil was slated for removal, the public would need to be informed of exactly why and how this is happening. This is what was done for the *Princess Kathleen* site, with excellent results. Although the *Princess Kathleen* is not applicable for memorial status, the public was educated as to the specifics of the defueling process. On this project, before work of any kind was performed by Global Diving and Salvage, an open house was arranged by the Coast Guard. Here they displayed ROV photos of the wreckage and images showing the oil sheening. Once the public was better informed, no one opposed the removal. After Global Diving and Salvage conducted an assessment of the ship, another open house was arranged, this time including an informative video entitled the "Saga of the *Princess Kathleen.*" This short film focused on the ship and the

[224] Angi M. Christensen and Sarah W. Meyers, "Macroscopic Observations of the Effects of Varying Fresh Water PH on Bone," *Journal of Forensic Science* 56, no. 2 (2011): 476.

work conducted to remove the oil.[225] By keeping the public informed as to the defueling progress, those who may protest the removal were given a forum to express their concerns. Most importantly, however, the open house allows the public to feel as though they are part of the process, rather than detached. Interestingly, in this case, the public felt such a connection with the project after the defueling was completed, that it was decided to leave the landing plates attached to the hull of the ship. Citizens interested in the project felt as though this process had become part of the ship's history and should thus be remembered as part of its evolution.[226]

It is apparent that any defueling project undertaken on the USS *Arizona* would have considerably more public image problems to contend with than did the *Princess Kathleen*. Despite this, the process of full disclosure with the public could potentially ease the tension. As was done in Alaska, informing all interested parties of exactly what was occurring on the historic wreck, and why, could allow citizens to feel as though they were participating in the decision concerning the ship.

ROYAL OAK

The first British warship to be lost in World War II was the *Royal Oak.* She sank on October 14, 1939 when the submarine U-47 found its way into the Scapa Flow home fleet base. Three torpedoes were shot into the battleship's hull, sinking it in less than 15 minutes (see image 21). Of the 1208 crew members, only 375 survived the sinking. When the ship sank, it was carrying approximately 3,000 tons of oil. The remaining oil leaked at a steady rate from the ship through hull breaches until the early 1990s. The ship's condition changed, however, in 1996 when oil was found in the surrounding Orkney beaches. Upon investigation, oil leakage from the wreck was found to have vastly increased from 100 liters (26.42 gallons) per day to 300-500

[225] The video can be found on Global Diving and Salvage's website at <http://www.gdiving.com/news/345>.
[226] "Interview".

liters (79.25-132.09 gallons) per day. This equates to 1.5 tons of oil per week. In 2000, it was determined that 96 percent of the total amount of oil in UK waters had originated from the *Royal Oak*.[227]

The site of the HMS *Royal Oak* is the largest official British war tomb. Much like the USS *Arizona*, this made defueling the ship controversial, with the Ministry of Defense reluctant to disturb the wreck. Multiple fisheries and local wildlife however, were in danger of being affected by the oil loss. Because of this, the local authorities in Orkney threatened legal action against the Ministry of Defense. This led the Ministry to conduct an extensive environmental study, influencing the decision to remove the oil.[228]

Prior to the defueling of the *Royal Oak*, several remediation efforts were attempted, all of which ultimately failed. Metal plates and sandbags were ineffectively secured to the hull in an attempt to quell the oil release. A much pricier option was a $300,000 stainless steel umbrella placed over the leaking wreck. The tidal action at the site made this remediation effort also inadequate. The Orkney region initiated the final action on the site before the defueling was undertaken. Large oil absorbing booms were attached to a fish cage anchored above the wreck. While each of these methods may have been temporarily helpful, they were not found to be long-term solutions. In 2001, at the cost of many millions of dollars, the *Royal Oak* was defueled. Using the hot-tap method also utilized on the *Princess Kathleen*, each of the fuel tanks was attached to a one-way valve to remove the oil. After the process was concluded, 1,500 tons of oil were still estimated to remain beyond reach within the ship.[229]

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[227] Michel et al., "Potentially Polluting,".
[228] Ibid.
[229] Ibid.

Many similarities exist between the case of the *Royal Oak* and the USS *Arizona*. Both of these historic wrecks are the gravesites for hundreds of sailors.[230] This obviously affects the defueling measures the government is willing to take. The difference in the situation of the two ships, however, is in the issue of the amount of oil being lost on a daily basis. The *Royal Oak* was leaking more than ten times more oil each day than is the bleeding Pearl Harbor battleship.[231] While this is not the situation currently, it is possible that this rate of loss is the future for the *Arizona*. If this becomes the case, the *Royal Oak* study could be crucial to a full understanding of the situation.

USS MISSISSINEWA

On November 20, 1944 in Micronesia, a Japanese suicide torpedo called a Kaiten struck the USS *Mississinewa*, an American oiler (see image 22). After burning from the 3,418 pound warhead explosion, the *Mississinewa* sank, with 63 U.S. sailors onboard.[232] The ship was 553 feet long and totaled 24,425 tons. It sank upside down in 130 feet of water, and remained there until it was rediscovered by sport divers in 2001.[233] In July of the same year, a storm ripped through the area and destabilized the wreck. Suddenly, sheening began to appear in the surrounding waters of the lagoon. After a multi-disciplinary study of the ship's structure, it was found to be leaking in excess of 1,000 liters (264.17 gallons) per day.[234]

Remediation efforts came into play after the primary leaking event. In 2002, the United States paid $4,000,000 to patch the USS *Mississinewa's* leakage points, thereby temporarily

[230] Stillwell, 225-259; Michel et al., "Potentially Polluting,".
[231] Michel et al., "Potentially Polluting,"; Russell and Murphy, "Long Term Monitering".
[232] Bob Fulleman and Ron Fulleman, "U.S.S. Mississinewa, AO-59," USS Mississinewa AO-59, November 12, 2009, Brief History, accessed June 25, 2011, http://www.ussmississinewa.com/home.html.
[233] U.S. Navy, *U.S. Navy Salvage Report*, Introduction and Background.
[234] U.S. Navy, *U.S. Navy Salvage Report*, Introduction and Background., Nadia Kamm, "An Overview of Pollution from Shipwrecks" (diss.), Second World War Shipwrecks, accessed June 25, 2011, http://lawspace.law.uct.ac.za/dspace/bitstream/2165/353/1/KMMNAD001.pdf.

sealing in the 18,000,000 liters (4,755,96.94 gallons) of oil remaining on the ship.[235] To do this, multiple operations had to take place. A four-inch pipe leaking from the valve was capped and installed with a new blanking flange. Another larger 12-inch pipe was found to be leaking, and was also plugged. A patch was utilized when a 24-inch long crack was found traversing the hull plating at the #3 wing tank on the starboard side. Lastly, after seven oil tanks were sampled and plugged, 3,400 gallons (12,870 liters) of oil and 7,400 gallons (28,012 liters) of oil-contaminated seawater were removed from the wreck.[236]

From January 28 to March 1, 2003, approximately one year after the efforts to patch the wreck, defueling was successfully completed on the *Mississinewa.* To gain access to the internal tanks, Broco® ultrathermic rods were used to cut an area from the hull large enough to allow diver access.[237] In total, approximately 1.8 million gallons (6,813,741.21 liters) were removed from the inner and outer tanks of the wreck. This equates to a removal of 99 percent of the original fuel oil supply during this operation. Oil removed from the wreck was then transported to Singapore to be sold. The oil profits were recycled into the defueling project to offset some of the operational costs.[238]

As previously mentioned, the USS *Mississinewa* is the gravesite of sixty-three sailors. Similar to what would likely occur on the USS *Arizona*, multiple public relation problems arose due to the disruption of the site. Because of this, the United States pledged to work only in areas that would have been unmanned at the time of the sinking. This could be done because the ship had settled upside down. Despite the 80-112 foot (24.38-36.14 meter) depths of the wreck, the

[235] Kamm, “An Overview of Pollution”, Second World War Shipwrecks.
[236] U.S. Navy, *U.S. Navy Salvage Report,* 2002 Operations.
[237] "Broco Industrial Ultrathermic Rods," STRONG Welding Products, Inc. - Home of Broco, Inc., Rankin Industries and Strong Welding, 2010, accessed June 26, 2011, http://www.broco-rankin.com/broco/i_ultrathermicrods.cfm., U.S. Navy, *U.S. Navy Salvage Report,* 4-3.2 Mississinewa Dive Plan.
[238] U.S. Navy, *U.S. Navy Salvage Report,* Introduction and Background.

defueling process was relatively simple. In total, twenty-three tanks were hot-tapped to remove the oil from the ship.[239]

The FEA model for the USS *Arizona* identifies the stresses that have accumulated since the sinking, and that will continue until the predicted hull corruption in 2240.[240] This model, however, does not account for the high probability overtime of a storm affecting the USS *Arizona's* stability. It is possible, much like the USS *Mississinewa*, that the *Arizona* could suffer from a significant environmental incident, thereby greatly increasing its leakage rate.

The way in which the oil was removed from the wreck of the *Mississinewa* may not be applicable to the work that may be required on the USS *Arizona*, due to the inverted positioning of the *Mississinewa*.[241] Nevertheless, aspects of the *Mississinewa* defueling can be used to achieve a result best suited for Pearl Harbor. Because the situation at Pearl Harbor is not deemed urgent due to the relative stability of the ship, it may be possible to utilize the patch strategies originally used on the *Mississinewa.* While this was only a temporary fix for this ship because of its high leakage rate, it may be a possibility for the slowly leaking *Arizona.* If a patch did not work and a situation occurred that forced oil removal, the cost of the process could be potentially offset by selling the oil, much like in the situation of the *Mississinewa.*[242]

Each of these case studies is comparable to situations that the USS *Arizona* may encounter over time. By combining these similar wreckage events with the data taken specifically from the USS *Arizona*, it is possible to create a more complete picture of the ship at this time and into the future. If a catastrophic situation were to occur with the USS *Arizona*, it is possible that studying the cases presented here could provide a more positive outcome. More

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[239] U.S. Navy, *U.S. Navy Salvage Report,* War Graves Considerations, 2003 Oil Removal Mission Tasking, Overview of 2003 Operations.
[240] Foecke, 10.
[241] U.S. Navy, *U.S. Navy Salvage Report,* War Graves Considerations.
[242] U.S. Navy, *U.S. Navy Salvage Report,* Introduction and Background.

importantly though, all of this information is beneficial to assist in the decision of whether or not the USS *Arizona's* oil should be removed or remediated, a conclusion which will be further investigated in the following chapter.

Chapter 3: The Potential Future of the USS *Arizona*

While the previous chapters have focused on the history of the USS *Arizona*, the data surrounding its corrosion, and how the *Arizona* relates to similar wrecks, this chapter will theorize a possible future of the site. To do this, the best and worst case scenarios surrounding the ship's inevitable collapse will be examined in detail. These will be created by extending the current data focused on the USS *Arizona* into the future, including information that could potentially harm or benefit the wreck.

In 2002, a detailed corrosion study was conducted on the USS *Arizona*, both above and below the mud line. Corrosion rate measurements from the port side were taken at 5 feet (1.52 meters), 19.5 feet (5.94 meters), 26 feet (7.92 meters), and 34 feet (10.36 meters) below the surface of the water. The starboard side rates are not included here, as the port side rates are generally higher. The highest corrosion rates were found 5 feet (1.52 meters) below the surface. Here, the ship corrodes at a rate of approximately 0.15 mm (0.00598 inches) per year. The ship's original hull thickness here was 0.5 inches (12.7 mm). This corrosion rate would account for a loss of 0.425 inches (10.80 mm), or 85 percent loss of the hull structure as of the year 2012. According to these data, a 90 percent loss in this area is expected to occur as early as the year 2016.[243]

At the deeper point of 19.5 feet (5.94 meters), the ship's corrosion rates slowed significantly. Here, the steel was corroding at a rate of 0.08 mm (0.00343 inches) per year. As of 2012, the ship would have lost 0.24 inches (6.10 mm), for a current hull thickness of 0.66 inches (16.76 mm). This would equate to a current (2012) loss of 27 percent from the original

[243] Johnson et al., USS Arizona Pt.1, 2-5.

0.9 inch (22.86 mm) hull thickness. In the year 2177, the hull will theoretically be reduced to 0.09 inches (2.29 mm), which equates to a 90 percent hull thickness loss.[244]

At 26 feet (9.92) below the surface, the corrosion rate again slows, although not as dramatically. This depth displayed a loss of 0.025 mm (0.00108 inches) per year. As of 2012, the ship has lost 0.077 inches (1.96 mm), for a current hull thickness of 0.423 inches (10.74). This equates to only a 15 percent loss of hull thickness. According to this research, a 90 percent hull thickness loss at 26 feet (9.92 meters) would occur in the approximate year 2358, 417 years after the attack at Pearl Harbor. [245]

The final depth included in the port side corrosion study was 34 feet (10.36 meters). Here, the metal was corroding at a very similar rate as the metal at 26 feet (9.92 meters). The corrosion rate at 34 feet (10.36 meters) is 0.00110 inches (0.028 mm). This equals a 2012 thickness of .0547 inches (13.89 mm), or a 12 percent loss since the sinking. When extrapolated, this would show a 90 percent loss of hull structure at this depth in the year 2452[246]

The previous chapter introduced a finite element analysis (FEA) model that stated the USS *Arizona* would slowly lose its structural integrity until approximately the year 2240, by which time the ship would have lost 90 percent of its hull structure. The data to create the FEA model were meticulously gathered and entered to create what the researchers hoped would be a very accurate view into the future of the *Arizona.* As the previous chapter explains however, this is likely to be a best case scenario. The FEA model presents the 80-foot expanse that was studied as a solid piece of steel, instead of riveted as it actually is. As previously shown, in many cases the rivets are the first areas to corrode on steel-hulled ships.[247]

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[244] Ibid.
[245] Ibid.
[246] Ibid.
[247] Foecke et al., 3-10.

The data presented by the FEA model do not consistently match the data from the corrosion study when extrapolated into the future (see image 23). According to the corrosion study, 90 percent of the uppermost areas of the ship, which lie only 5 feet (1.52 meters) below the surface, will be lost by 2016.[248] In contrast, the FEA model predicts the significantly more optimistic occurrence of corrosion of the upper decks between the years 2120 and 2180.[249] Another example of more conservative corrosion rates than the FEA model was at 19.5 feet (5.94 meters) below the surface. According to the FEA model, even in the year 2240, when the ship is projected to have lost approximately 90 percent of its structure, i.e. internal and external components of the ship, the hull is still fairly intact at approximately 19.5 feet (5.94 meters) below the surface.[250] When extrapolated, however, the corrosion rates taken from the *Arizona* show a 90 percent loss of hull structure at this point in the approximate year 2177.[251] The FEA model prediction ends at 2240, by which year the researchers propose that the USS *Arizona* will have lost 90 percent of its total hull structure. Because of this, it is not possible to conclude when the model proposes the 90 percent loss at depths of 26 and 34 feet (9.92 and 10.36 meters) below the surface will occur, because in the year 2240 these areas are theoretically still fairly intact. Despite this, the FEA model predicts that by the year 2240, the double bottom will have collapsed, although the interior of the wreck will remain.[252] This difference in rates possibly reflects the fact that the corrosion data is taken purely from the hull, while the FEA model represents data from throughout the exterior and interior of the ship. In addition, the FEA model

[248] Johnson et al., USS Arizona Pt.1, 5.
[249] Foecke et al., 9-10.
[250] Foecke et al., 10.
[251] Johnson et al., USS Arizona Pt.1, 5.
[252] Foecke et al., 10.

was created in a near monolith style, where some of the individual pieces of the wreck were modeled as singular pieces.[253]

Best Case Scenario

To create a best case scenario for the USS *Arizona*, multiple aspects of the ship's deterioration must be taken into account. Although corrosion data from the wreckage shows that sections near the surface could lose 90 percent of their hull structure as early as 2016, lower areas show slower levels of deterioration, losing 90 percent between the years 2177 and 2452.[254] Therefore, certain aspects of the wreckage could prolong the amount of time that the *Arizona* would remain structurally sound. These will be included here within the best case scenario.

When the USS *Arizona* sank on December 7th 1941, it did so vertically, and into approximately 25 feet of mud. The positioning of this wreck now assists in its stability. While ships that sink in an inverted position are the most stable, those that sit on their sides corrode the quickest. This is because the structure of the ship was not engineered to support its own weight in that manner. Sinking in an upright position prevents undue stress on the hull, which should allow the wreck to persist longer than if it had settled on its side.[255]

According to John Riley, a diver who was well-respected by the maritime archaeological community for his knowledge of steel wrecks, ships that sink in an upright manner tend to bury themselves into soft bottoms such as sand or mud, up to what would have been the ship's previous waterline.[256] This holds true for the USS *Arizona*. The wreck lies in approximately 30 feet of water and 25 feet (7.62 meters) of mud. Originally, the *Arizona* had a draft of 28 feet 10 inches (7.87 meters). This would mean that the *Arizona* followed the waterline theory and sank

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[253] Ibid 4.
[254] Johnson et al., USS Arizona Pt.1, 5.
[255] Jacqueline Piero, "The Deterioration of Ferrous Hulled Shipwrecks" (thesis, East Carolina University, 2004), 72.
[256] Ibid, 72.

into the harbor floor to its approximate previous waterline.[257] The rate of corrosion of the *Arizona* is greatly slowed by the amount of mud in which it is sitting.[258]

Riley's theories do not pertain only to the sinking patterns of ships. He also covers how corrosion is most likely to occur after the ship sinks. According to Riley, when a ship has settled to its previous waterline, the decking begins to corrode away.[259] This is currently what is occurring on the *Arizona,* where the highest level of corrosion is found on the decking, only 5 feet (1.52 meters) below the surface of the water.[260] Riley also states that as the decking is corroded, the hull sides will peel away from the wreck in areas where the ship is not bulkheaded.[261] The fact that the USS *Arizona* is heavily bulkheaded throughout, should assist in holding the sides of the ship together more securely than would occur if the interior was lacking this important structural component.[262] Riley's theory on corrosion patterns concludes with his observation of several heavily corroded ships. According to this theory, when ships do finally lose their sides, the bow, stern, and machinery tend to remain.[263] Although this is not the current state of the USS *Arizona*, this conclusion points toward remnants surviving long after the majority of the hull has been lost.

The fact that the USS *Arizona* sank in the fairly protected area of Pearl Harbor also lends heavily to its slowed level of corrosion. Research into the deterioration of shipwrecks throughout the world has revealed one of the most important variables to be the amount of water movement surrounding the wreckage. This became apparent when shipwrecks near each other showed similar levels of corrosion. Examples of this are the wreckage sites in Scapa Flow and

[257] Johnson et al., USS Arizona Pt.1, 5.
[258] Ibid.
[259] Piero,72.
[260] Johnson et al., USS Arizona Pt.1, 5.
[261] Piero, 72.
[262] Russell and Murphy, "Long-Term Monitoring", 392.
[263] Piero, 73.

Truk Lagoon. Both of these areas are famous for their well-preserved groups of wrecks. Jacqueline Piero, in her master's corrosion study, proposes that this is because of the nature of the areas where the ships wrecked. These areas are well sheltered by landmasses and have calm water.[264] As presented in the previous chapter, the USS *Arizona* is also protected in a calm fan-shaped harbor.[265] According to the data presented by the Truk Lagoon and Scapa Flow studies, the USS *Arizona'*s rate of natural corrosion should have been slowed by reduced aquatic abrasion due to the generally calm water.

The lack of excessive movement in the harbor is not the only aspect of the water that is assisting in the USS *Arizona's* stability. The average water temperature surrounding the Honolulu, Oahu, area is 78.2°F (25.7°C).[266] In general, warm water increases the level of corrosion at a site. For water with any given oxygen concentration, the corrosion rate tends to double for every 55°F (30°C) increase in temperature.[267] While this relatively warm water does generally increase the speed of corrosion, it also helps create more concretions on the surface of the steel. Concretions or other biofouling agents create barriers that prevent oxygen and ion migration, which would depolarize anodic areas.[268] In addition to adding a barrier between the ship and agents that would corrode the hull, organisms that attach to the hull also help to support it. These organisms encrust the surface of the USS *Arizona*, providing it with added rigidity and strength that it may have lacked otherwise.[269]

[264] Ibid, 95.
[265] "Pearl Harbor and Honolulu Harbor Hurricane Haven Study (U) UNCLASSIFIED,".
[266] "Coastal Water Temperature Table," US NODC Coastal Water Temperature Guide, February 23, 2012, Honolulu, Oahu Island, accessed February 23, 2012, http://www.nodc.noaa.gov/dsdt/cwtg/hawaii.html.
[267] Robert Winston Revie and Herbert Henry Uhlig, *Corrosion and Corrosion Control: An Introduction to Corrosion Science and Engineering*, 4th ed. (Hoboken, NJ: Wiley-Interscience, 2008), 120.
[268] Piero, 63.
[269] R. Daniel, "Appendix A: USS Arizona Memorial resource overview" 2006, *In*: HaySmith, L., F. L. Klasner, S. H. Stephens, and G. H. Dicus, Pacific Island Network vital signs monitoring plan, Natural Resource Report NPS/PACN/NRR—2006/003 National Park Service, Fort Collins, Colorado,5.

While concretions and biofouling agents can be beneficial to the preservation of the USS *Arizona's* hull, sulfate reducers and methanogenic bacteria can live within mud and concretions and eat away at metal hulled ships. In a case where these bacteria are acting upon a ship, the amount of corrosion caused is proportional to the amount of bacteria present. The small amount of corrosion found at and below the mud line on the USS *Arizona* suggests that these bacterial agents are either minimal or non-existent.[270] This is likely because of the anti-fouling paint on the hull below the waterline.[271]

The mud surrounding the USS *Arizona* is also helping the wreck survive in another way. When wrecks sink into softer materials such as mud or sand, they are well supported. Mud works as a cushion to protect the wreck from a multitude of environmental factors, such as inclement weather or wave action. Ships found in rocky environments can easily be tossed and broken on the hard bottom.[272]

Although the rivets on the USS *Arizona* will inevitably deteriorate to the point of structural failure, the mud may possibly assist in holding the ship together. While the areas above the mud line would collapse outwardly, the hull plating below the mud line would likely be held secure. This is reinforced by the GPS data taken from the USS *Arizona,* which shows that the wreckage is stable and has made no discernible movement.[273] In addition to this, although no data are currently available on the corrosion rate of the rivets below the mud line, logically, these would be expected also to be corroding at a slower rate. The loss of hull plating above the mud line would be detrimental to the stability of the hull. It should be kept in mind

[270] Piero, 64; Johnson et al., USS Arizona Pt.1, 5.
[271] Rodgers, Personal Communication.
[272] Piero, 67.
[273] Russell and Murphy, "Long-Term Monitoring", 392-399.

however, in the case of the oil tanks, that since all of the tanks are currently below the mud line, the majority of the oil would still be contained.[274]

Also assisting in the retention of the hull stability is its lack of superstructure.[275] In the years following the sinking of the *Arizona*, much of the ship's superstructure, including the fore and main masts, stern aircraft crane, conning tower, all anti-aircraft guns including the 5-inch/51 caliber, and 5-inch/25 caliber guns, the after turrets with their guns and ammunition, and what remained of turret two, were removed to be used elsewhere.[276] Although the original reason behind the removal of the ship's superstructure was not weight reduction, the lack of weight has lessened the pressure on the fragile decking. Currently, the deck is corroding at a rate of 0.15 mm (0.00598 inches) per year.[277] Had the ship's superstructure been retained, the deck beams would likely have already collapsed inward, as the weakened metal would not be sufficient to hold up the weight.

When the current corrosion rates are extrapolated out to a 90 percent loss of hull structure, the greatest fear, beyond the loss of the historic wreck, is the potential outpouring of thousands of gallons of oil. As previously addressed, the areas of the wreck closest to the surface will degrade first, in the year 2016 approximately. This could potentially increase the oil leakage rate since the oil that is currently pooling within the wreck would more quickly reach the surface. At 19.5 feet below the surface, however, the corrosion rate is significantly slowed. Here, it is estimated that 90 percent of the hull structure will be lost by 2177.[278] Although it is unlikely, if the ship were to release the remaining oil in the year 2177, it would expel between 356,664.5 and 456,664.5 gallons (1,350,122 and 1,728,663.18 liters) into the small harbor. This

[274] Ibid, 392.
[275] Piero, 74.
[276] Furlong, *Salvage Operations on USS ARIZONA.*
[277] Johnson et al., USS Arizona Pt.1, 5.
[278] Ibid, 2-5.

was determined by extrapolating the 9 liters per day (2.38 gallon) leakage rate out to one year, then multiplying this by 165 (which is the number of years from 2012 to 2177), then subtracting that value from the estimated amount retained within the *Arizona* today, which is between 500,000 and 600,000 gallons (1,892,705.89 and 2,271247.07 liters).[279] Although by this point in the future the ship would have lost approximately 143,335.5 gallons (542,583.9), this amount of oil is still quite significant and could be potentially devastating if not cleaned quickly. Thankfully, though, it is unlikely that the totality of the remaining oil would be released at this time, even if the hull in this area were to catastrophically fail.

The lower areas under the mud line, where the vast majority of the oil resides, are corroding at the slowest rate. According to corrosion rates, at 26 feet (9.92 meters) below the surface, the ship will lose 90 percent of its hull structure by the year 2358, while 90 percent will be lost at 34 feet (10.36 meters) in the approximate year 2452. In the year 2358, the USS *Arizona* will still have between 202,035.9 and 302,035.9 gallons (764,789.08 and 1,143,330.26 liters) remaining. When the ship at 34 feet (10.36 meters) is predicted to reach 90 percent corrosion, the ship will still contain approximately between 117,772 and 217,772 gallons (445,815.52 and 824,356.7 liters). Again, this was conservatively determined by multiplying the *Arizona's* daily leakage rate by 365 days and then multiplying that number by either 343 or 440, which is the numbers of years between 2012 and 2391, and 2012 and 2452 respectively. This product was then subtracted from the estimated amount of oil in the ship now.[280] While this total is approximately a third of the estimated amount held today, it is still a large amount of oil that would need to be quickly cleaned to avoid damage to the harbor.

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[279] Ibid; Russell and Murphy, "Long-Term Monitoring", 408-466.
[280] Ibid.

Currently the contingency plan for an oil spill in Pearl Harbor includes oil-absorbing materials, booms, and skimmers. All of these would be used in the event of a significant spill from the USS *Arizona.* Oil-absorbing booms would also be placed at the mouth of Pearl Harbor to prevent the oil from reaching the ocean or nearby wetlands that house a multitude of endangered birds.[281] As mentioned in the previous chapter, the *Nestucca* sank in 1988 in the Pacific Ocean, releasing 230,000 gallons (870 644.7 liters) of oil that contaminated coastal areas of both Washington and Vancouver. The spill was quickly addressed with the use of oil-absorbing pads and pom-poms. Because of factors that included the rapid response, little evidence of the oil remained when the areas were studied in 1990.[282] The USS *Arizona* Memorial is an emotionally charged site, with plans in place to quickly remediate any problems should a failure occur.[283]

When the eventual collapse of the wreckage does occur, this possibly will not mean the end of the Pearl Harbor Memorial. As a hull degrades, the artifacts tend to fall into the remaining structure of the wreckage, thus keeping the associated items together.[284] The lack of significant water movement would also assist in keeping the artifacts together. While the USS *Arizona* Memorial would not be the same as it was in the past, or is currently, it would continue to be an organic and ever-changing representation of the tragedy of the *Arizona* disaster, and Pearl Harbor attack as a whole.

Worst Case Scenario

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[281] SAPA, "60 Years On, Divers Scout the USS Arizona," Http://www.news24.com/xArchive/Archive/60-years-on-divers-scout-the-USS-Arizona-20010623, June 23, 2001, accessed February 25, 2012, News 24.
[282] Graham, 302.
[283] SAPA, “60 Years On”.
[284] *Iron Ships and Steam Shipwrecks: Papers From the First Australian Seminar on the Management of Iron Vessels and Steam Shipwrecks.* by The Western Australian Maritime Museum. Perth, Australia.

While a best case scenario is obviously the most comforting option, potentially more useful information can be derived from examining the USS *Arizona* in a more hazardous situation. This could be an event ranging from premature failure of the steel to a storm ripping through the harbor. Multiple scenarios will be presented here that could negatively affect the current stability of the USS *Arizona.*

When the USS *Arizona* was bombed near the No. 2 turret, the ship exploded and began to burn. The ship then continued to burn for three days, until December 10th 1941.[285] When steel is exposed to temperatures in excess of 932°F (500°C), the strength of the metal is decreased by approximately 40 percent. In comparison, fires in steel buildings can reach temperatures in excess of 1,800°F (982°C).[286] Although the heat of the fire that burned through the *Arizona* is unknown, it burned for three days, making weakening of the steel a significant factor.[287] Because of this, the ship could possibly fail before the predicted 90 percent hull loss because of the fire-weakened steel.

In addition, the method used to harden the rivets of the *Arizona* immediately lowered both their tensile and fatigue strengths, when compared to unheated attachment methods such as bolts.[288] Riveting also lowers the steel's ductility, making it more brittle. Each year, the rivet shafts are losing 2.1 mils per year (mpy) (0.053 mm), while the heads of the rivets lose the much higher amount of 5.3 mpy (0.135 mm). When compared to the hull plating, the rivet shafts are corroding at a rate between the 19.5 foot (5.94 meter) corrosion rate, and the 26-34 foot (7.92-10.36 meter) corrosion rate. In contrast, the heads of the rivets are corroding at a rate nearly

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[285] Stillwell, 225-259; Camp, 89.
[286] Emil Venere, "Engineers Test Effects of Fire on Steel Structures, Nuclear Plant Design," PhysOrg.com, September 2, 2011, accessed March 01, 2012, http://www.physorg.com/news/2011-09-effects-steel-nuclear.html.
[287] Stillwell, 225-259.
[288] Peter Maranian, *Reducing Brittle and Fatigue Failures in Steel Structures* (Reston, VA: American Society of Civil Engineers, 2010), 147.

comparable to the rate of corrosion on the *Arizona*'s hull only 5 feet (1.52 meters) below the surface. This would equate to a .371 inch (9.4 mm) loss at the head of the rivet, and a .147 inch (3.73 mm) loss on the shaft since the sinking.[289]

Currently, no information exists for the original dimensions of the rivets used on the USS *Arizona*, but scaled photos taken in 2009 show the widest portion of the shaft to be approximately 1 inch (25.4 mm), while the narrowest area was only .75 inches (19.05 mm). (see image 15) The head of the rivet is widest at approximately 1.75 inches (44.45 mm), though it narrows at the top to slightly under an inch. By reversing the corrosion rate, the shaft can be assumed to have been originally 1.14 inches (28.96 mm), with the narrow section likely due to corrosion, while the head ranged from 2.1 inches (53.34 mm) at the widest, to 1.2 (30.48 mm) inches near the top of the head. Assuming that the corrosion rate of the rivets is going to continue at a steady rate, this would mean that the wide portion of the shaft of the rivet would lose approximately 60 percent of its structure by the year 2266, while the narrow section, if it is representative of the *Arizona*'s rivets as a whole, would lose 60 percent by the year 2195. The rivet head would lose this same percentage in the year 2178 for the thick flange portion, and in the year 2076 for the thinner section of the head. These approximate years were found by multiplying the perceived original thicknesses of the different areas of the rivets by .6 (60 percent). This number was then divided by the corrosion rate, which equaled the number of years required to achieve a 60 percent loss. Lastly, the number of years was then added to 1941, the year of the sinking.[290] Sixty percent was chosen, in this case, instead of 90 percent because of the amount of stress that is put on the rivets. This pressure could cause the rivets to shear off

[289] Saunders and Hamilton, Metallurgical Analysis. Corrosion Rate Analysis.
[290] Ibid.

at a lower point of structural failure than would be expected for the larger hull plating if a significant event such as a storm occurred.

Pearl Harbor—and Hawaii in general—when compared to other coastal areas, is fairly protected from hurricanes. The Central Pacific Hurricane Center (CPHC) identifies storms between the Longitudes of 140°W and 180°, and warns the Hawaiian Islands when necessary. Dangerous weather on the islands include gale force winds (39-54 mph), tropical storm force winds (cyclonic winds 39-73 mph), and hurricane force winds (74 mph or greater). Five levels of hurricanes are recognized, with the weakest storm considered a hurricane having winds ranging from 74-95 mph; this is referred to as a category 1. A category 2 has winds ranging from 96-110 mph, while a category 3 has 111-130 mph winds. The winds in a category 4 storm start at 131 and go to 155 mph. Anything above 155 mph is a category 5. Categories 3-5 are all considered major storms.[291]

Although the warm water surrounding the Hawaiian Islands could potentially support at least a category 4 hurricane, these rarely occur near the islands. This is because of the Tropical Upper Tropospheric Trough (TUTT). The TUTT creates high winds around the islands, which are detrimental to development or support of a hurricane or tropical storm. Because of this, most lower-level storms go either north, south, or through the islands, but do not develop further.[292]

While the TUTT does help the Islands avoid many storms, it does not keep them all away. Hawaii is particularly vulnerable to storms that originate from the Southwest and move North. These storms occur when the TUTT is displaced slightly to the North, which was more

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[291] CG Captain of the Port, "Maritime Heavy Weather and Hurricane Plan," Department of Homeland Security, July 2009, Key Terms and Definitions, accessed March 1, 2012, https://homeport.uscg.mil/cgi-bin/st/portal/uscg_docs/MyCG/Editorial/20101206/!FULL_Appendix1_Maritime.pdf?id=4822d57965c77e9237d7f384b8dd9eafd769ba08&user_id=-7425&cur_time=Thu%20Mar%2001%2000:17:50%20EST%202012&source=CONTENT.

[292] Steve Lyons, "Hawaii's Savior from Hurricanes," The Weather Channel, July 7, 2007, accessed February 25, 2012, http://www.weather.com/blog/weather/8_13056.html.

common during the El Nino years. Some notable examples of this were Hurricane Iniki in 1992, Hurricane Iwa in 1982, and Hurricane Nina in 1957. [293] Of these, the most devastating was Iniki, which struck Kauai, and affected Oahu. In total, the storm caused 2.3 billion dollars in property damage and took the lives of three people. In Oahu, wind gusts reached upwards of 160 miles per hour, and water overtook Waikiki Beach, flooding some of the hotels located there.[294]

In very rare cases, a hurricane can hit from the East or Southeast. This generally happens when a hurricane comes from a low latitude then takes a Northwest or North-Northwest turn towards the islands, thus encountering the TUTT for only a short period of time. Because of this, the storm is unable to weaken from the strong TUTT wind shear.[295] This was the case when Hurricane Dot approached the Hawaiian Islands in 1959. This storm caused only minor damage in Oahu, but six million dollars of agricultural damage to Kauai.[296]

Although hurricanes are fairly rare in the Hawaiian Islands, it is possible for a powerful hurricane to hit Oahu. If this were to happen, the effect on the USS *Arizona* Memorial could be devastating. While the muddy bottom would help to cushion the wreckage in the event of a storm, a strong enough hurricane could possibly dislodge the *Arizona.*[297] Even though the rivets are not currently near their critical structure point, in a worst case scenario, if a powerful storm were to hit the ship, the hull plates could be separated, thereby destabilizing the ship.[298]

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[293] Lyons, "Hawaii's Savior".
[294] Al Kamen, "Hawaii Hurricane Devastates Kauai," Washington Post, September 13, 1992, accessed February 25, 2012, http://www.washingtonpost.com/wp-srv/weather/hurricane/poststories/iniki.htm; Steven Businger, "Hurricanes In Hawaii," School of Ocean and Earth Science and Technology, September 25, 1998, accessed February 25, 2012, http://www.soest.hawaii.edu/met/Faculty/businger/poster/hurricane/.
[295] Lyons, "Hawaii's Savior".
[296] "Hawaii's Hurricane History," Hawaii News Now, accessed February 25, 2012, http://www.hawaiinewsnow.com/Global/story.asp?s=6921152; Jack Williams, "Hurricanes Rarely Hit Hawaii," USA Today, December 16, 2004, accessed February 25, 2012, http://www.usatoday.com/weather/hurricane/2003-09-01-hawaii-hurricnes_x.htm.
[297] Piero, 67.
[298] Johnson et al., USS Arizona Pt.1, 2-4.

In an absolutely worst case scenario, if a storm were to dislodge some of the ship's hull plating, the result could possibly puncture a portion or all of the oil tanks that are currently buried deep within the ship. If the oil tanks were compromised, the previously mentioned current amount of between 500,000 and 600,000 gallons (1,892,705.89 and 2,271247.07 liters) of bunker C oil would be released into the harbor. This situation could be similar to the *Erika* disaster presented in the previous chapter. The 3,700 ton tanker *Erika* sank in 1999 during a winter storm. As the ship went down, it broke in half, releasing thousands of tons of oil. Although the ship sank only approximately 30 miles off of the nearest coast, and began leaking oil almost immediately, cleaning efforts were greatly hindered by storms. Because of this, nearly 249 miles of the French coastline was damaged by the oil that originated from the *Erika*.[299]

If oil were to be catastrophically released into the harbor, it would not be the first time that the area has encountered this type of problem. In 1987, 100,000 gallons of jet fuel was released from a pipeline into the Middle Loch portion of Pearl Harbor. This spill caused damage to the surrounding environment. Leaf yellowing, defoliation, and the partial loss of approximately 9.5 acres of mangroves were all outcomes of this release.[300] Although jet fuel is much lighter than the heavy #6 fuel oil that is currently within the *Arizona*, the spill impeded normal actions at the Naval Base for two months.[301]

Although the spill was not as large, the effects of the Chevron pipeline spill into Waiau Stream and Pearl Harbor were significantly more devastating. At 1:30 am on May 14, 1996, a section of the Chevron pipeline, which had been weakened from outside erosion, gave way

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[299] Kamm, "An Overview of Pollution", Oil; "The Scandal of the Erika," BBC News, August 16, 2000, accessed February 27, 2012, http://news.bbc.co.uk/2/hi/programmes/correspondent/883110.stm.
[300] Steve Coles, "Marine Communities and Introduced Species in Pearl Harbor, Oahu, Hawai'i," in *The Environment in Asia Pacific Harbours*, ed. Eric Wolanski (Dordrecht: Springer, 2006), 214.
[301] Tony Perry, "Pearl Harbor Oil Leak Is Precious to Some, but a Worry to Others," Www.SFGate.com, February 12, 2007, accessed March 04, 2012, http://www.sfgate.com/cgi-bin/article.cgi?f=/c/a/2007/02/12/MNGIMO33FC1.DTL.

releasing heavy #6 bunker oil into the Waiau Stream. Here, the oil sank until it met the heavier salt water of Pearl Harbor, afterwhich it rose to the surface. The pipeline continued to leak for two weeks, for a total loss of approximately 41,244 gallons (156,125.52 liters) of oil that, within the first six days of the leakage event, covered 2,290 acres of open water. Immediate effects of the spill included the closing of Pearl Harbor to navigation traffic and boating and fishing, and the closing of the USS *Arizona* Memorial. Sections of the jogging and biking paths surrounding East Loch also had to be closed to public traffic. The multiple different types of shorelines, including mudflats, rocky shores, mangroves, sandy beaches, riprap, seawalls, and piers along the perimeter of both Pearl Harbor and Waiau Stream were affected by the spill. In total, 25 acres of intertidal habitat in East Loch, Pearl Harbor were oiled because of the 1996 spill. When efforts were begun to clean the oil, booms, skimmers, chemical agents, pompoms, and pads were all utilized. High power steam cleaners were also used on the shorelines to remove the oil. At the USS *Arizona* Monument, all visitation was ceased from May14-18th, and restricted from May 18-22nd. Despite the cleaning that occurred between May 14-22nd, the shoreline near the monument continued to show an iridescent sheen in excess of a month.[302]

Although the efforts to clean the shoreline were all meant to be beneficial, many of the procedures, such as the high power washing, and removal of vegetation, further damaged the shore. Exacerbating the problem, particularly bad rainstorms occurred in November of the same year, which led to extensive erosion at the visitor's center. Because of this, emergency efforts were needed, and sandbags were employed to fill in eroded areas.[303]

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302 United States, Department of the Interior, Department of Fish and Wildlife, *Final Restoration Plan and Environmental Assessment for the May 14, 1996 Chevron Pipeline Oil Spill into Waiau Stream and Pearl Harbor, Oahu, Hawaii*, by Pearl Harbor Natural Resource Trustees, November 1999, Overview, 3.2.1 Intertidal Habitat, accessed March 4, 2012, http://www.gc.noaa.gov/gc-rp/phfnlea1.htm.
303 Department of the Interior, *Final Restoration Plan,* Overview.

The shorelines were much more heavily affected than the macrofauna in the surrounding environment. Only a minimal number of animals including several crabs, two mynah birds, one tilapia, four pufferfish, two freshwater prawns, and one young dove, were actually reported to have been found affected by oil contamination.[304] Despite this, reports stated that the possibility of further animal exposure was high, and that it was not out of the question to believe that the area could take up to ten years for a full recovery from the damage.[305]

The USS *Arizona* Memorial's, oil recovery contingency plan would not be as effective if booms and skimmers could not be utilized quickly because of a storm. The Coast Guard though does have plans in place for the Hawaiian Islands in the face of a hurricane. Depending on the strength of the storm, the Captain of the Port (COTP) may decide to restrict or deny entry to oil tankers. Although the COTP will continually monitor the area during the storm, only actions that preserve the lives of Coast Guard personnel and equipment will take place. Directly after a devastating storm, the official contingency plan places emphasis on four key missions, one of which is spill response.[306] By comparing the Coast Guard contingency plan to the events that occurred after the 1996 oil spill, it is clear that although the agencies are prepared for a spill, the effects could still be significant.

If a storm were to dislodge or break apart the *Arizona* for any reason, between 500,000 and 600,000 gallons (1,892,705.89 and 2,271247.07 liters) of oil would be deposited into the small harbor.[307] Although the current amount of oil leaking into the harbor has a negligible

[304] Department of the Interior, *Final Restoration Plan,* 3.1.5 Marine/Estuarine Biota (Finfish, Shellfish and Invertebrates), 3.2.1.3 Evidence of Injury.
[305] Department of the Interior, *Final Restoration Plan,* 3.2.1.1 Resources at Risk, 3.2.1.4 Recovery Period.
[306] CG Captain of the Port, "Maritime Heavy Weather and Hurricane Plan," Response During and Immediately After the Storm.
[307] Rodgers, 7.; Tim Foecke et al., "Investigating Archaeological Site Formation Processes".

effect on the environment, a release of this large amount of oil would have a definite effect on Pearl Harbor, as witnessed by the significantly smaller spill that occurred in 1996.[308]

As previously mentioned, the oil tanker *Mississinewa* was sunk in Micronesia in 1944, after being hit by a Japanese suicide torpedo. This wreck was leaking at a fairly steady rate until July 2, 2001, when a typhoon ripped through the area, destabilizing the wreck.[309] After a multi-disciplinary study, the ship was found to be leaking in excess of 1,000 liters (264 gallons) per day.[310] Despite the high winds that plagued the site, divers were able to assess the wreck and patch three areas that were leaking oil with concrete plugs and epoxy.[311]

The *Mississinewa* wreck and remediation has multiple attributes that correspond to the *Arizona.* Oil leaking from the *Mississinewa* was greatly increased after a storm. This could be the same outcome as the *Arizona* if a storm were to rip through the area. It was comforting to see that remediation efforts were completed on the *Mississinewa*, even in less than ideal weather conditions.[312]

It does not take a hurricane though to initiate or increase leakage rates on wrecks. Multiple sites, including the *White Whale* and *Costa Concordia,* have shown increased leakage rates during periods of heavy winds.[313] The *White Whale* was a 141 foot (43 meter) long supply vessel that sank off the coast of Umm Al-Quwain, United Arab Emirates.[314] The *White Whale*

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[308] Graham, 372-375; Department of the Interior, *Final Restoration Plan*, Overview.
[309] Jason Rice, ed., "WWII Tanker Leaks Oil in Ulithi," *Yap EPA News* 3 (December 10, 2001): 1, accessed March 1, 2012, http://epayap.orgfree.com/EPAnewsVol3.pdf.
[310] U.S. Navy, *U.S. Navy Salvage Report,* Introduction and Background., Nadia Kamm, "An Overview of Pollution from Shipwrecks" (diss.), Second World War Shipwrecks
[311] Rice, 1.
[312] Ibid.
[313] "White Whale," Shipwreck Log, October 22, 2011, accessed March 01, 2012, http://www.shipwrecklog.com/log/2011/10/white-whale/; "Fuel from the Costa Concordia Starts to Be Pumped out," BBC News, February 13, 2012, accessed March 04, 2012, http://www.bbc.co.uk/newsround/17016186.
[314] "White Whale," Shipwreck Log.

was carrying 440 tonnes (139,814 gallons) of diesel when it sank in 98 feet of water.[315] The Minister, Dr. Mariam Al Shanasi, stated that the ship was not releasing diesel into the surrounding environment, but that the initial thought to salvage the vessel had not been abandoned.[316] Contrary to governmental reports, local fishermen visually identified a trail of diesel originating from the wreck. Because of this, many refused to fish in the area due to the fear of potential contamination of their catch.[317] Although the Ministry of Environment and Water continued to reassure the public that the wreck was not hazardous, Dubai Ship Building was commissioned to retrieve the vessel.[318]

The diesel leak reported by the fishermen was noticed after multiple days of rough seas had occurred over the wreck site. This points to the potential of storms weaker than hurricanes affecting leakage rates. The *Arizona* has been identified to leak more during days when there is more wave action at the site. Vessel wake and windy days can cause the wreck to disgorge a higher volume of oil than it does when the environment is calm.[319] The *White Whale* is significantly deeper than the *Arizona,* so storms would logically affect the *Arizona* more intensely.[320]

Conclusion

The USS *Arizona* is in an important point in its history. Presented in this chapter are possible aspects of the wreck and its environment that assist both in its preservation and in its possible demise. As presented by both the corrosion data and the FEA model, the majority of the

[315] Yasin Kakande, "Shipwreck Is Leaking Oil, Fishermen Claim," The National, February 7, 2012, accessed March 03, 2012, http://www.thenational.ae/news/uae-news/environment/shipwreck-is-leaking-oil-fishermen-claim.
[316] Yasin Kakande, "Minister: No Diesel Leak on White Whale," The National, February 6, 2012, accessed March 03, 2012, http://www.thenational.ae/news/uae-news/environment/minister-no-diesel-leak-on-white-whale.
[317] Kakande, "Shipwreck Is Leaking Oil, Fishermen Claim,".
[318] Yasin Kakande, "Wreckage of Sunken Ship to Be Salvaged," The National, February 18, 2012, accessed March 03, 2012, http://www.thenational.ae/news/uae-news/wreckage-of-sunken-ship-to-be-salvaged.
[319] Yasin Kakande, "Shipwreck Is Leaking Oil, Fishermen Claim,"; Russell and Murphy, “Long-Term Monitoring”, 413.
[320] Kakande, "Shipwreck Is Leaking Oil, Fishermen Claim,".

remaining ship is not in immediate danger of catastrophic hull failure due to corrosion.[321] Both the mud that surrounds the *Arizona*, and the harbor environment, help preserve the wreck. Because of this, a best case scenario most closely follows the FEA model of corrosion, where the ship continues at a relatively steady rate of loss. Also, one could hope that Pearl Harbor storms would be minimal, and would not greatly affect the wreck site, or if a storm did occur, that any oil loss could be quickly cleaned before it reached the fragile shoreline.

In contrast, however, situations may arise that could negatively affect the wreck and the surrounding harbor. Hurricanes are not frequent near the Hawaiian Islands, although current data shows the water there could support at least a category 4 hurricane.[322] However, as both the *White Whale* and the *Arizona* itself have shown, it does not take a large storm to increase the leakage rate of a sunken oil containing vessel.[323] In addition to a storm, the fire that raged through the ship on December 7, 1941 must also be taken into account as it certainly affected the stability of the steel.[324] This increases the chance that the ship will collapse under its own weight long before the corrosion has reached 90 percent.

While it is possible that neither the best nor worse case scenarios will ever come to pass, it is necessary to understand these possibilities. It would be wonderful if the ship could retain its structure for the years projected by the corrosion rates or the FEA model, although the possibility of a premature collapse cannot be, and is not being ignored. In many ways, it is more important to study a worst case scenario, because this works to prepare those involved for a situation where the *Arizona* is lost much sooner than currently expected. The two extremes presented here will

[321]Johnson et al., USS Arizona Pt.1, 2-5.
[322] Lyons, "Hawaii's Savior from Hurricanes,".
[323] Russell and Murphy, “Long-Term Monitoring”, 413; Yasin Kakande, "Shipwreck Is Leaking Oil, Fishermen Claim,"
[324] Stillwell, 225-259; Camp, 89; Venere, "Engineers Test Effects of Fire on Steel Structures”.

be reflected in the next chapter, entitled Conclusions and Recommendations for the USS *Arizona* Memorial Site.

Chapter 4: Conclusions and Recommendations for the Future of the USS Arizona

Information presented up to this point has been focused on answering the thesis questions presented in the introduction: Is the wreck of the USS *Arizona* in danger of structural failure on the bottom of Pearl Harbor, and what will be the ship's continuing legacy and effect on the harbor's environment? This chapter will present the importance of the wreck, along with recommendations for the future of the site.

The site of the USS *Arizona* has the power to evoke a multitude of emotions. Although the war that started for America with the bombing at Pearl Harbor has long since ended, the strong feelings that most feel upon visiting the USS *Arizona* site are apparent. This aspect of the wreck has greatly affected its current state. There are many seemingly forgotten wrecks, carrying thousands of gallons of oil, throughout the world today. The majority of these anonymous wrecks are not nearly as closely tied to deep-seated emotions as Battleship *Arizona.* Had any one of these other wrecks begun to leak oil in an area as small as Pearl Harbor, it likely would have been removed or defueled years ago. The emotions tied to the *Arizona* wreck greatly affect the actions performed on its deteriorating wreckage. Fear of disturbing a war tomb or causing detrimental change to a National Monument makes it difficult for those associated with the site to work without the fear of controversy.

Controversy at the site can come from both sides of the site preservation and the oil loss issues. Some believe that while the site is important to the country's history and should thus be treated with respect, the environment needs to take precedence. For this proactive group, the oil that looms within the *Arizona* presents a problem that is too potentially catastrophic to ignore.

Because of this, they believe that the oil must be removed for continued preservation of the site, as well as the environment.

On the other side of the issue are those who believe that the sacredness of the site trumps any potential damage that the oil is causing. This more reactively focused group holds that the wreck should be allowed to deteriorate through the natural processes of the harbor. Entering the wreck for any reason is frowned upon because of the potential to disturb the final resting place of approximately nine hundred sailors.[325]

These strong feelings highlight the historical importance of the site. December 7, 1941 was a vital point in the history of the United States as it marked the entrance of the country into World War II. In addition to this, the wreck of the USS *Arizona* serves as a memorial, not only for the men lost on the *Arizona*, but for the Pearl Harbor attack as a whole. Even the building of the memorial has ties to history involving celebrities such as Elvis Presley who sponsored a charity concert to raise a portion of the funds.[326]

Scientifically, the USS *Arizona* is a vital source of information concerning steel hull site formation processes. Because of the ship's previously mentioned emotional and historical significance, scientists from multiple disciplines have meticulously studied the wreck. This provides the scientific world, as a whole, with a truly amazing data set. Important information can be gleaned from the wreck of the *Arizona,* ranging from the effects of shallow, relatively still water on the corrosion rates of a steel wreck, to the way in which a ship will slowly collapse, and much more.

Environmentally, the USS *Arizona* presents the scientific world with an incredible amount of information about the effects of heavy bunker oil on a small, protected area over a

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[325] Stillwell, 225-259.
[326] Ibid, 281-286.

long period of time. As shown in the previous chapters, the amount of oil currently exuded by the wreck is having a negligible effect on the surrounding harbor.[327] This, though, would not be the case if a large spill were to occur, as was confirmed by the 1996 Chevron spill in Pearl Harbor. While the Chevron leak produced a total of approximately 41,244 gallons of oil, i.e., only 6-8 percent of what is approximated to be contained within the *Arizona* today, it had a dramatic effect on the environment and the Harbor shoreline.[328] From this, the potential effects of a catastrophic hull failure of the USS *Arizona* can be predicted.

There are of course, situations that could affect the wreck's stability that were not included in this thesis in detail. One such possibility would be an earthquake. The Hawaiian Islands are made of volcanos, which greatly affect their stability. Oahu, the island on which Pearl Harbor lies, has two major volcanos, both of which are dormant.[329] Despite the volcanoes not being active, Oahu continues to experience fairly minor earthquakes approximately twice a year. In contrast the Big Island experiences vastly more earthquakes, with a minor one occurring nearly daily.[330] The last noteworthy earthquake occurred in Oahu on January 22, 2012. This quake registered 5.0 on the Richter scale. No reports of injury or damage were associated with this event.[331] It would be possible in theory though for a large enough earthquake to disrupt the stability of the USS *Arizona*. If the upper decks were to suddenly collapse, the additional weight could potentially destroy the lower areas of the wreck.

If a significant earthquake were to occur on the island of Oahu it could also affect the stability of the memorial. Surrounding the wreckage of the USS *Arizona* are cylindrical

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[327] Graham, 372.
[328] Department of the Interior, *Final Restoration Plan*, Overview.
[329] Rachel Klein, *Fodor's Oahu*, 3rd ed. (New York: Fodor's Travel Publications, 2010), 22.
[330]
[331] Associated Press, "Magnitude-5.0 Earthquake Shakes Hawaiian Island of Oahu," ABC15.com, January 22, 2012, accessed April 02, 2012, http://www.abc15.com/dpp/news/national/magnitude-50-earthquake-shakes-hawaiian-island-of-oahu.

reinforced concrete pylons which support the memorial. These are located approximately 6-10 feet from the exterior of the wreck. If an event such as an earthquake or hull failure occurred it is possible that the 14 inch case hardened steel plates could fail due to the continually deteriorating armor belt. These plates could separate from the sides of the wreck and damage or potentially break the pylons, thus compromising the stability of the monument. [332] Although significant data on the possibility of an earthquake was not included in this thesis, it is just one of many situations that could unexpectedly occur.

A thorough study of the USS *Arizona*'s current situation leads to the conclusion that the oil contained within the ship should presently be remediated rather than removed. This conclusion was not reached without a thorough investigation of the available data and corresponding case studies, or without significant caveats. The *Arizona,* as an artifact of the moment at which the United States entered World War II, is arguably one of the most important vessels in our nation's history. Because of that, no decision about its future should be reached haphazardly. Currently, the oil is not greatly affecting Pearl Harbor, and the hull shows no signs of imminent failure in areas surrounding oil containment bunkers. In addition, the amount of potential cost and detriment to the hull from complete defueling does not currently outweigh the fairly low possibility of a storm or other disaster occurring at the site. Despite this, there are suggestions for future work on the site that, in this author's opinion, should be utilized to protect the harbor from extensive oil damage.

Although the conclusion reached is that the USS *Arizona*'s oil should not currently be fully removed, this does not mean that the potential for a catastrophic oil spill has been eliminated. As the 2008 report from Mathew Russell and Larry Murphy indicates, the oil leakage rates were monitored in 1998, 2003, 2004, and 2006. In my opinion, the length of time

[332] Brad Rodgers, Personal Communication.

between monitoring is too broad and non-standardized. I believe that the USS *Arizona*'s oil leakage rate should be monitored more closely than it is now, since the ship is aging and deteriorating. Although the data show a significant increase in the oil leakage rate from the No. 4 barbette between 1994 and 1998, all of the eight reported leaks since then seem to have leveled off or even decreased. Because of the current stabilization of the leakage rate, I believe that it would be ideal for the ship to be monitored once per year. In addition to this, all eleven of the leakage points throughout the ship need to be included to obtain a full assessment of how much oil is escaping on a daily basis.[333]

This proposal however, only pertains to the ship if the leakage continues at its present steady rate. If at any point the rate of oil loss is seen to increase, it would be necessary to decrease the intervals between the monitoring sessions. If, after measuring the rate of leakage, the oil increase does not warrant removal at that time, monitoring should then be conducted annually, as the oil loss regains equilibrium.

While a consistent plan for monitoring the USS *Arizona*'s oil loss is important, there are other actions that could decelerate the oil leakage rate and potentially create a safer environment for the wreck. Currently, the oil being lost from the ship has been analyzed to be fairly weathered. As previously explained, this means that the oil is likely leaking into the internal structures of the ship before exiting through open ports and cracks. This, though, is not the case for the oil leaking from the area surrounding barbette #4, designated in Figure 5 by the aft most circle, and in Figure 2, indicated as "Location A." The oil emanating from this area was found to be unweathered, meaning it is coming directly from an original area of oil containment. These are potentially the most dangerous of the 11 leakage points. Unlike a failure of the other leakage areas throughout the ship, which would simply leak out the oil that had accumulated, a failure of

[333]Russell and Murphy, "Long-term Monitoring", 413.

the deck and hull plating in the area of barbette #4 would expel all of the oil remaining in those bunkers supplying this leak.[334]

Because of the danger associated with this specific leakage area, I propose that one or multiple patches, such as those attached to the *Mississinewa*, be placed over this leak after an investigation to determine the bunkers from which the leak was originating. Although this method was unsuccessful for the *Mississinewa* because of its high leakage rate of over a thousand liters per day, I believe that it would be significantly more effective in the case of the USS *Arizona.*[335] This solution would not only be less expensive than a complete defueling, but would also be significantly less invasive.

If a patch was deemed unhelpful in this area, it may be possible to execute a partial defueling on the barbette #4 leakage points. Because oil is escaping to the surface, it should not be difficult to reverse the process to determine exactly which bunker(s) is expelling oil. Removing the oil would then likely be as straightforward as inserting a modified hot-tap into the offending bunkers and cleansing the tanks, a process that was conducted on the *Princess Kathleen*, and explained in the previous chapter.[336]

The hull itself also needs periodic monitoring. The current rates of corrosion have been extrapolated into the future, by both this thesis and the FEA model, to produce a potential date of collapse for the historic wreck. Nevertheless, monitoring is still crucial to determine if these predictions are being proven correct. Because the hull rates are more stable than the fluctuating leakage rates, investigations of the hull need not be conducted as frequently as those for oil loss. If a significant event such as a storm were to occur at the site, the hull stability would need to be

[334] Russell and Murphy, "Oil Removal", 406-407.
[335] U.S. Navy, *U.S. Navy Salvage Report,* 2002 Operations.
[336] "Interview."

further assessed, both initially after the incident and frequently afterwards, until the wreck showed that it had regained a state of relative equilibrium.

Sudden changes in the hull stability could be caused by a storm. Hurricanes, the most likely type of natural disaster to affect Hawaii, generally come with sufficient warning to evacuate potential victims. This however would not be the case for the shipwreck. There is little that could be done to protect the *Arizona* from a potentially hazardous storm. Half across the world from Pearl Harbor, the fear of hurricanes affecting the Beaufort Inlet Wreck, also tentatively known as Blackbeard's Queen Anne's Revenge, prompted the state of North Carolina to create berms to protect the site. Built in 2006, these artificial sand bars were placed 420 feet (128 meters) from the wreck and span 600 feet (182.88 meters) long and 200 feet (60.96 meters) wide.[337] As of 2011, and the assessment of the effects of Hurricane Irene, the berms were seen as continuing to produce beneficial results. Sand scour and storm damage were both minimized by the berms.[338] For the *Arizona,* the time between when a hurricane warning is issued and the storm actually hitting could be dedicated to fine tuning a disaster recovery plan and potentially creating berms such as what were used on the Beaufort Inlet Wreck. In addition to this, stabilization of the ship, if needed, would be crucial, as would be a review of the existing emergency planning to contain and remove expelled oil.

As presented in the previous chapter, the oil currently contained within the USS *Arizona* has the possibility of being hazardous to the environment if expelled in large amounts. Current visual and scientific studies of the environment surrounding the wreck are optimistic about the

[337] Willie Drye, ""Blackbeard's Ship" Wreck to Get Protection From Currents, Hurricanes," National Geographic, March 6, 2006, accessed March 22, 2012, http://news.nationalgeographic.com/news/2006/03/0306_060306_blackbeard.html.
[338] Jannette Pippin, "Queen Anne's Expedition under Way," News Source for Jacksonville, North Carolina, October 4, 2011, accessed March 22, 2012, http://www.jdnews.com/articles/carteret-95774-county-expedition.html.

amount of damage occurring.[339] As shown by the 1996 Chevron spill, if a large oil release were to occur, the No. 6 bunker oil spill would obviously need to be quickly mitigated.[340] Because of the minimal wave action in the harbor, and the PAH level of the oil, the fuel would likely remain on the surface, with only a minimal amount becoming water-soluble or combining with the sediment.[341] These features, along with a fast clean-up using booms to skim the oil from the surface of the water, would minimize the effect on the surrounding species, thereby avoiding a situation like the *Erika* spill.[342]

If, at some point in the future, the oil needed to be removed, a combination of what was executed on the *Mississinewa,* and what has already been done on the USS *Arizona* might be the best solution. On the *Mississinewa,* when defueling was determined to be the only option, it was completed in a manner that avoided potential human remains. This was possible because the ship had settled upside down on the seafloor, thus exposing the tanks to the defueling crew.[343] Currently, researchers working on the USS *Arizona* have conducted multiple ROV studies on portions of the internal structures of the ship. Although none of these identified any human remains, there is evidence that they could still be present.[344]

If the necessity arose that the ship had to be defueled, a high definition camera mounted on the ROV would aid researchers in avoiding possible human remains. A cutting implement, also mounted to the ROV, could maneuver in those areas too small or too dangerous for conventional divers. Lastly, a dredge head, such as the ZJS100 ROV Dredge Pump® made by

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[339] Russell and Murphy, "Oil Removal Versus Site Preservation,"421; Graham, 372.
[340] Department of the Interior, *Final Restoration Plan,* Overview
[341]Graham, 299 ; Cormack, 83; Graham, 374-375.
[342] Michel et al., “Potentially Polluting”, Oil.
[343] U.S. Navy, *U.S. Navy Salvage Report,* War Graves Considerations, 2003 Oil Removal Mission Tasking, Overview of 2003 Operations.
[344] Nakaso, "Memorial Gets Checkup,"; Christensen and Meyers, “Macroscopic Observations”.

Advanced Marine Innovation Technology Subsea Ltd., could be attached to the ROV to assist in any sediment removal that would inevitably be necessary.[345]

If defueling is ever deemed necessary, videos such as those made for the *Princess Kathleen* would be crucial to quell the anxiety that would likely be felt by the surrounding community, if not by the entire nation.[346] These informative movies would need to include thorough but engaging information on the ship's history, combined with why the defueling was necessary. This would need to be presented in a way that was both scientific and accessible to the general public. If an ROV was used and found no human remains in the work areas, these videos should also be used as part of the presentation. As the defueling progressed, there would invariably be publicity surrounding the event. This could be advantageous to the work being done if local and national news broadcasting networks were provided with updates and commentary from those working on the wreck, thereby helping the nation to feel more connected to the process. By showing the public that the decision to remove the oil was not arrived at easily, and that the work is being completed in a respectful manner, people's fears should be alleviated.

All of these recommendations are somewhat idealistic. There is likely neither a sufficient amount of money nor manpower at present to effectively conduct the remediation efforts presented here. However, while costly, these efforts would prevent disaster remediation and also assist in better educating the public regarding the continued stability of the USS *Arizona* and the oil which it currently contains. Much of the information that is easily accessible to the public is approximately three years old. Creating a forum, potentially associated with a social networking

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[345] "Advanced Marine Innovation UK ROV Dredge Pumps and Underwater Engineering," Advanced Marine Innovation Technology Subsea Ltd UK, ZJS100 ROV Dredge Pump, accessed March 21, 2012, http://www.advancedmarineinnovation.com/id8_dredging_pumps.htm.

[346] "Interview".

site such as Facebook, could inform the public as to both the leakage rates and the hull deterioration. By doing this, at least some of the fears associated with the remaining oil could potentially be alleviated. This more personal connection to the site could also increase the number of people who donate to the USS *Arizona* Memorial, thereby increasing the revenue that cyclically could be used to continue the ship's monitoring.

The USS *Arizona* will always be an important National Monument. Even if the ship must eventually be defueled, which may cause irreparable damage to its structural integrity, the feelings behind the ship's importance would still remain. Simply changing the shape of the monument should not and does not take away its emotional impact. Since little remediation is currently occurring, the ship is naturally continuing to change. For many that visit the memorial, this is not only satisfactory, but preferable. Unlike many sunken ships, which lend themselves to thoughts of treasure and wealth, the USS *Arizona* is currently and will forever be a tomb and reminder of national preparedness as well as a memorial to the men who lost their lives during the day which shall live in infamy.

Figure 1

Year	Number of Locations Measured	Average Total Amount Measured Per 24 Hours (quarts)	Average Total Amount Measured Per 24 Hours (liters)
1998	1	1	0.95
2003	2	2.1	2
2004	2	2.3	2.2
2006	8	9.5	9

Year	Location	Date	Amount	Time	Total per 24 hr. (qt.)	Total per 24 hr. (l)
1998	Oil hatch starboard of No.3 barbette	8/29/98	800 ml	22 hrs. 39 min.	0.9	0.85
1998	Oil hatch starboard of No.3 barbette	8/31/98	700 ml	27 hrs. 35 min.	0.64	0.61
1998	Oil hatch starboard of No.3 barbette	9/06/98	175 ml	3 hrs.	1.5	1.4
2003	Oil hatch starboard of No.4 barbette	11/18/03	42.5 oz.	24 hrs.	1.33	1.25
2003	Oil hatch starboard of No.4 barbette	11/19/03	42.5 oz.	24 hrs.	1.33	1.25
2003	Oil hatch starboard of No.3 barbette	11/20/03	16-24 oz.	24 hrs.	0.5-0.75	0.47-0.7
2004	Oil hatch starboard of No.4 barbette	11/09/04	14 oz.	6 hrs.	1.75	1.66
2004	Oil hatch starboard of No.3 barbette	11/11/04	16 oz.	24 hrs.	0.5	0.47
2006	Oil hatch starboard of No.4 barbette	06/20/06	5 oz.	4 hrs.	0.94	0.89
2006	Oil hatch starboard of No.4 barbette	06/21/06	5.2 oz.	4 hrs.	0.97	0.92
2006	Oil hatch starboard of No.3 barbette	06/23/06	10 oz.	24 hrs.	0.31	0.3
2006	Starboard of galley, on deck	06/24/06	5 oz.	24 hrs.	0.16	0.15
2006	Starboard of galley starboard bulkhead, forward of doorway	06/26/06	<1 oz.	48 hrs.	<0.016	<0.015
2006	Starboard gunwale, frame 68	06/28/06	8 oz.	24 hrs.	0.25	0.24
2006	Port, forward corner of vegetable locker	06/28/06	9.4 oz.	4 hrs.	1.8	1.7
2006	Port side of galley, on deck	06/29/06	5 oz.	3 hrs.	1	0.95
2006	Starboard side of galley, at transverse bulkhead between upper deck and main deck.	06/29/06	20 oz.	3 hrs.	5	4.7

Russell, Matthew A., and Larry Murphy. "Number of Oil Locations Measured and Amounts (top) and Oil Release Quantities by Year (bottom)." Digital image. Long Term Management Strategies for USS Arizona, A Submerged Cultural Resource in Pearl Harbor. Accessed November 14, 2010. http://www.history.navy.mil/branches/UA_ManagementUSS%20Arizona-c.pdf.

Figure 2

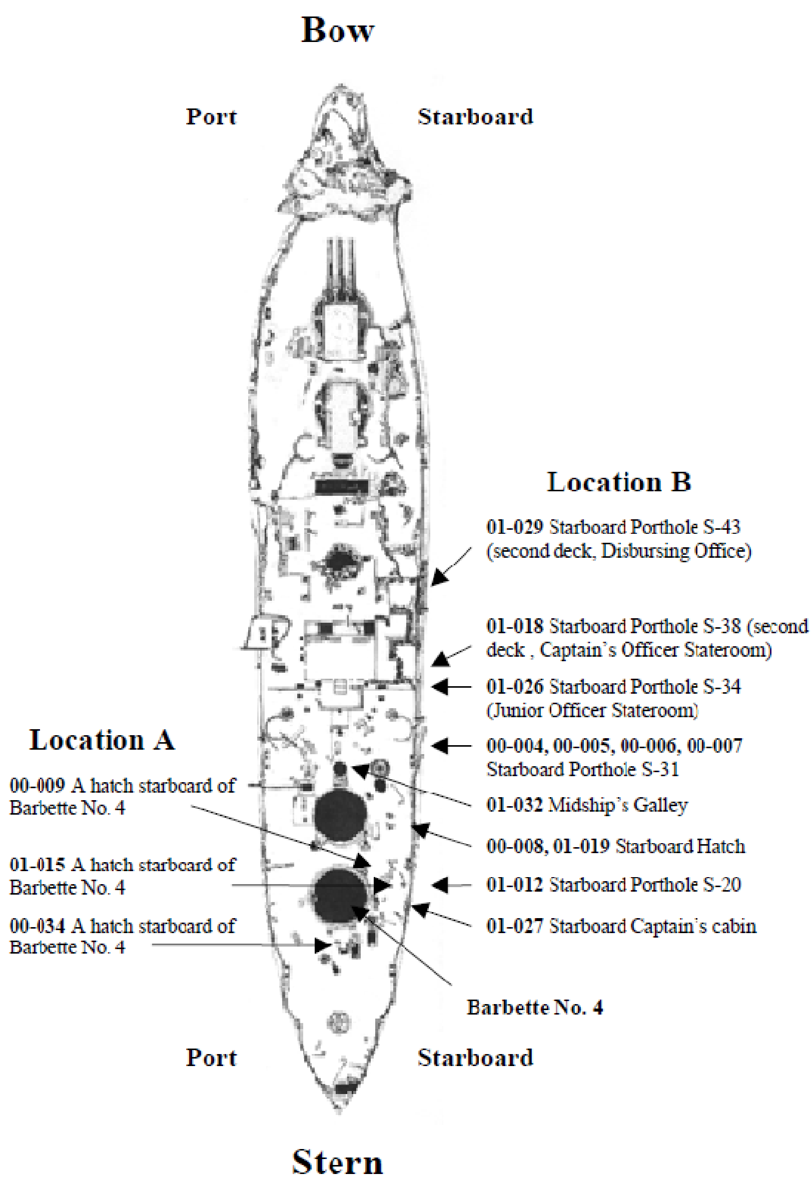


Figure 8.4. USS *Arizona* **sample locations for oil leaking from the ship. Location A (stern starboard hatches) and B (stern starboard portholes) represent two different general areas of the ship.**

Graham, Amanda. "USS Arizona Sample Locations." Digital image. Long Term Management Strategies for USS Arizona, A Submerged Cultural Resource in Pearl Harbor. Accessed November 14, 2010. http://www.history.navy.mil/branches/UA_ManagementUSS%20Arizona-c.pdf.

Figure 3

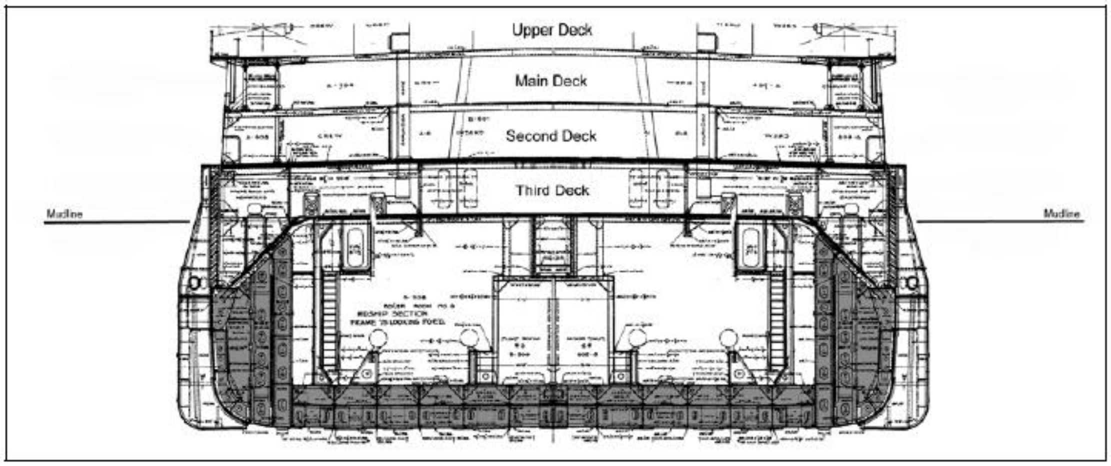


Figure 9. 2. ***Arizona*** **hull cross-section at frame 75. Dark areas are oil bunkers and the line indicates the current seabed level relative to the hull (Graphic by NPS-SRC).**

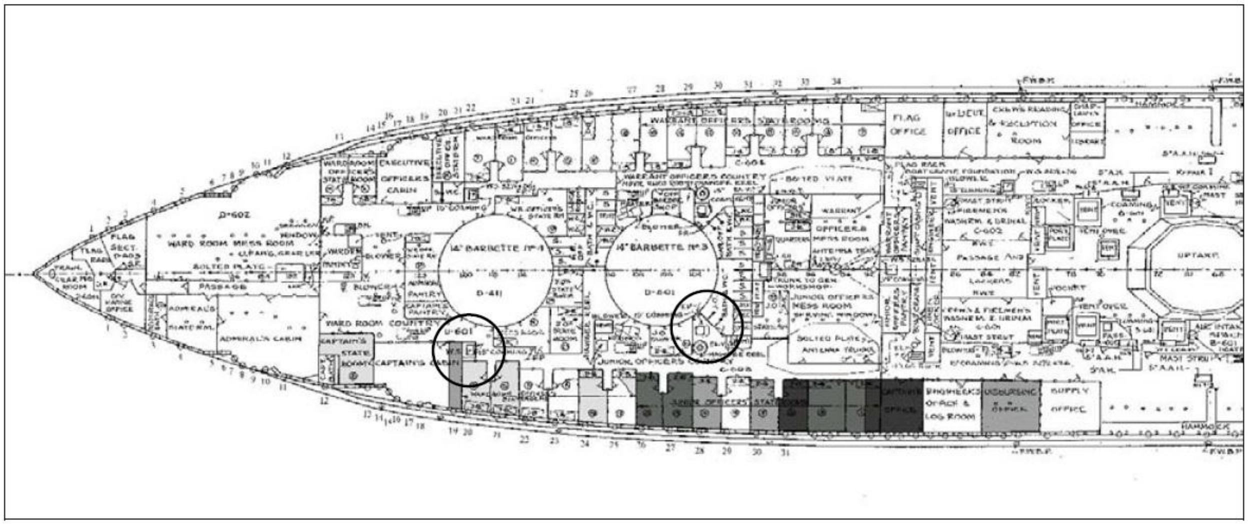
Russell, Matthew A., and Larry Murphy. "Arizona Hull Cross-Section at Frame 75." Digital image. Long Term Management Strategies for USS Arizona, A Submerged Cultural Resource in Pearl Harbor. Accessed November 14, 2010. http://www.history.navy.mil/branches/UA_ManagementUSS%20Arizona-c.pdf.

Figure 4

	BB 38 & 39	*BB 36 & 37*	*Change*
Displacement, full load	32,500	28,400	+ 4,100 tons
Displacement, normal	31,400	27,500	+ 3,900 tons
Length, overall	608'	583'	+ 25 feet
Length, pp	600'	575'	+ 25 feet
Beam, load WL	97'	95'-2''	+ 1'-10''
Draft, mean	28'-10''	28'-6''	+ 4 inches
Draft, max.	29'-10''	29'-7''	+ 3 inches
Main Battery	12-14''	10-14''	+ 2 guns
Speed	21.0 knots	20.53 knots	+ .47 knots

Friedman, et. al. "Comparisons Between Pennsylvania Class Ships and Nevada Class Ships". *USS Arizona (BB 39).* Annapolis, Maryland: Leeward Publications, 1978, 4.

Figure 5

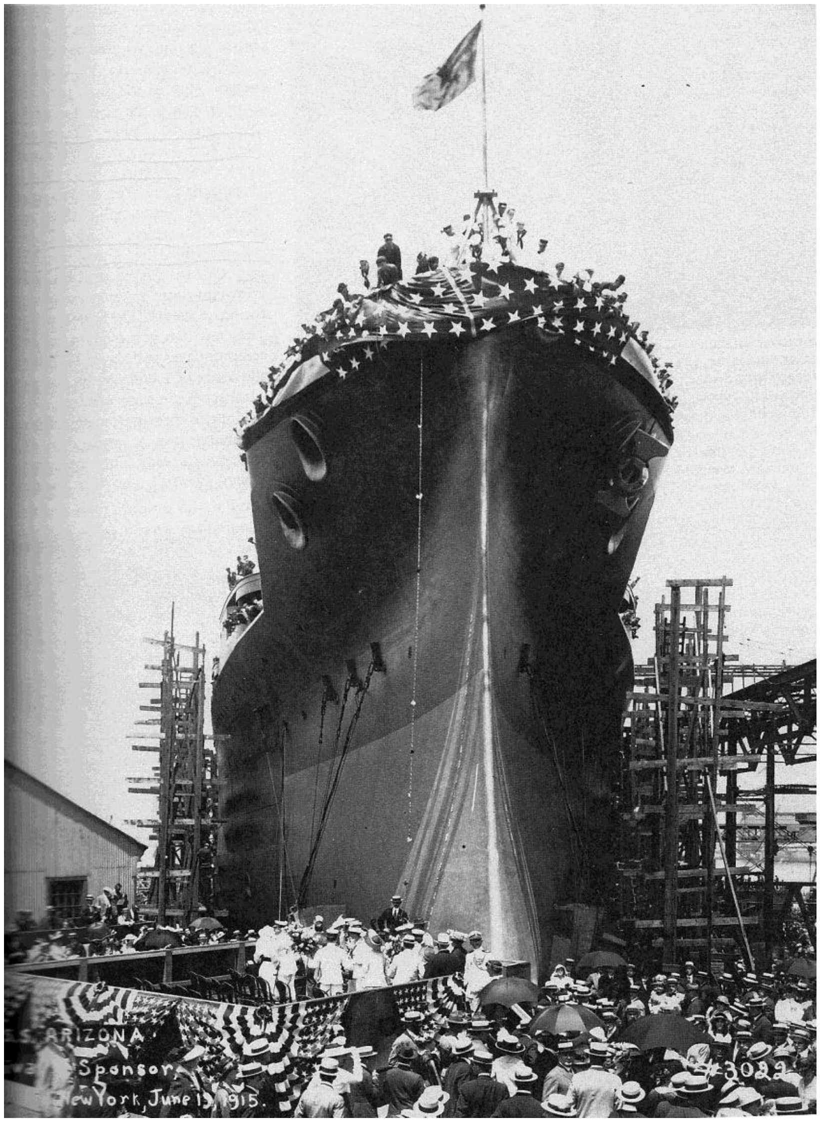


NPS-SRC. "Illustration of thickness of overhead oil on *Arizona's* starboard second deck (stern to left). Relative darkness represents thickness of oil in each cabin overhead, and hatches releasing oil are circled". *Long-Term Monitoring Program: Structure, Oil, Artifacts and Environment.* Santa Fe, New Mexico: National Park Service Submerged Resource Center, 2008.

Image 1

Stillwell, Paul. “Roosevelt and Henry Williams Jr. at Keel Laying Ceremony”. *Battleship Arizona.* Maryland: Naval Institute Press, 1991,4.

Image 2

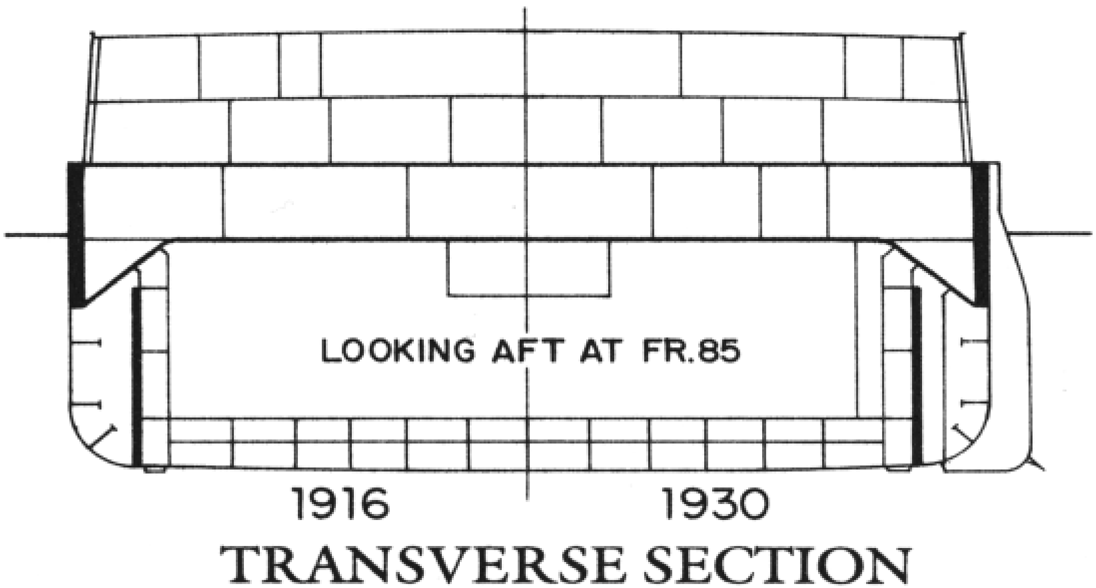


Stillwell, Paul. “USS Arizona: Arizona Sponsor”. *Battleship Arizona.* Annapolis, Maryland: Naval Institute Press, 1991,11.

Image 3

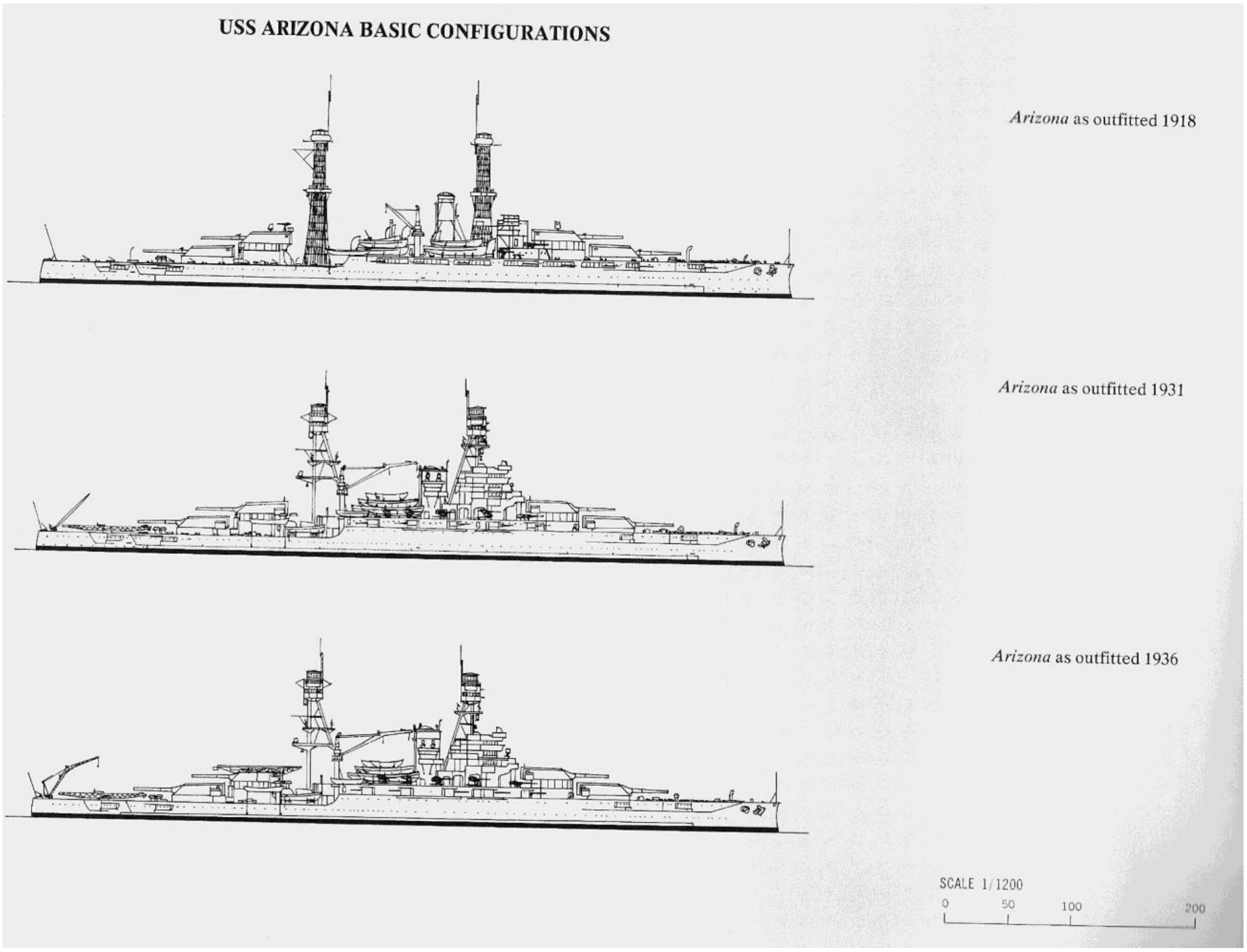
Stillwell, Paul. "USS *Arizona* Steaming Down the River." *Battleship Arizona.* Annapolis, Maryland: Naval Institute Press, 1991,19.

Image 4



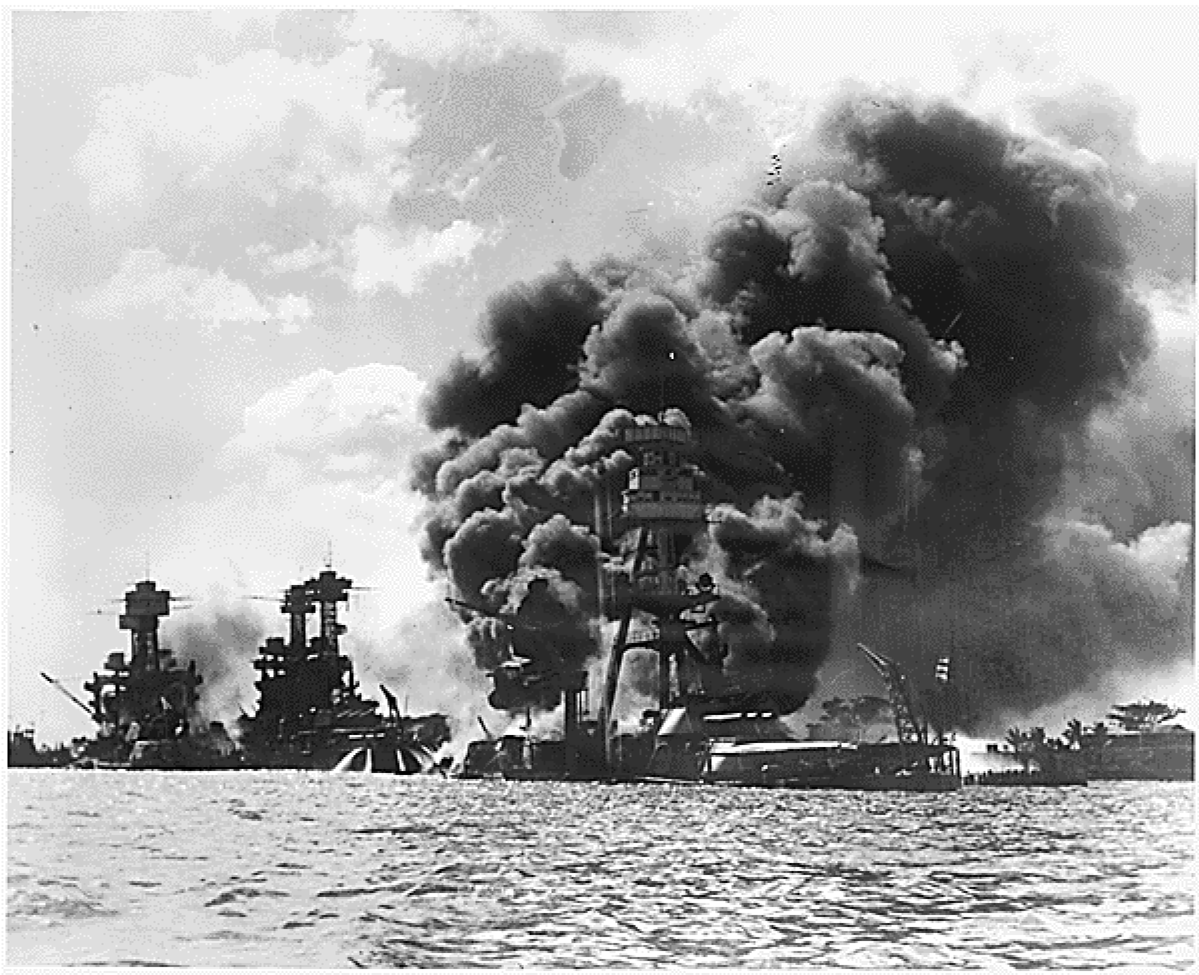
Murphy, Larry and Matt Russell. “Transverse hull sections showing structural changes during 1929–1931 refit”. “Historical Record: USS *Arizona* Battle Damage and Salvage” *Long-Term Management Strategies for USS Arizona, a Submerged Cultural Resource in Pearl Harbor,* 2008, 42.

Image 5



Friedman et al. "USS *Arizona* refits over time". *USS Arizona (BB 39).* Annapolis, Maryland: Leeward Publications, 1978.

Image 6



US District Court for the District of Hawaii. "Three Capital Ships Afire and Sinking, the USS West Virginia, the USS Tennessee, and the USS Arizona after the Japanese Attack on Pearl Harbor on December 7, 1941." Digital image. National Archives. Accessed August 24, 2011. http://research.archives.gov/accesswebapp/faces/showDetail?file=Item_196243.xml&loc=39.

Image 7

Stillwell, Paul. “Battleship Fuel Pipeline”. *USS Arizona.* Maryland: Naval Institute Press, 1991, 240.

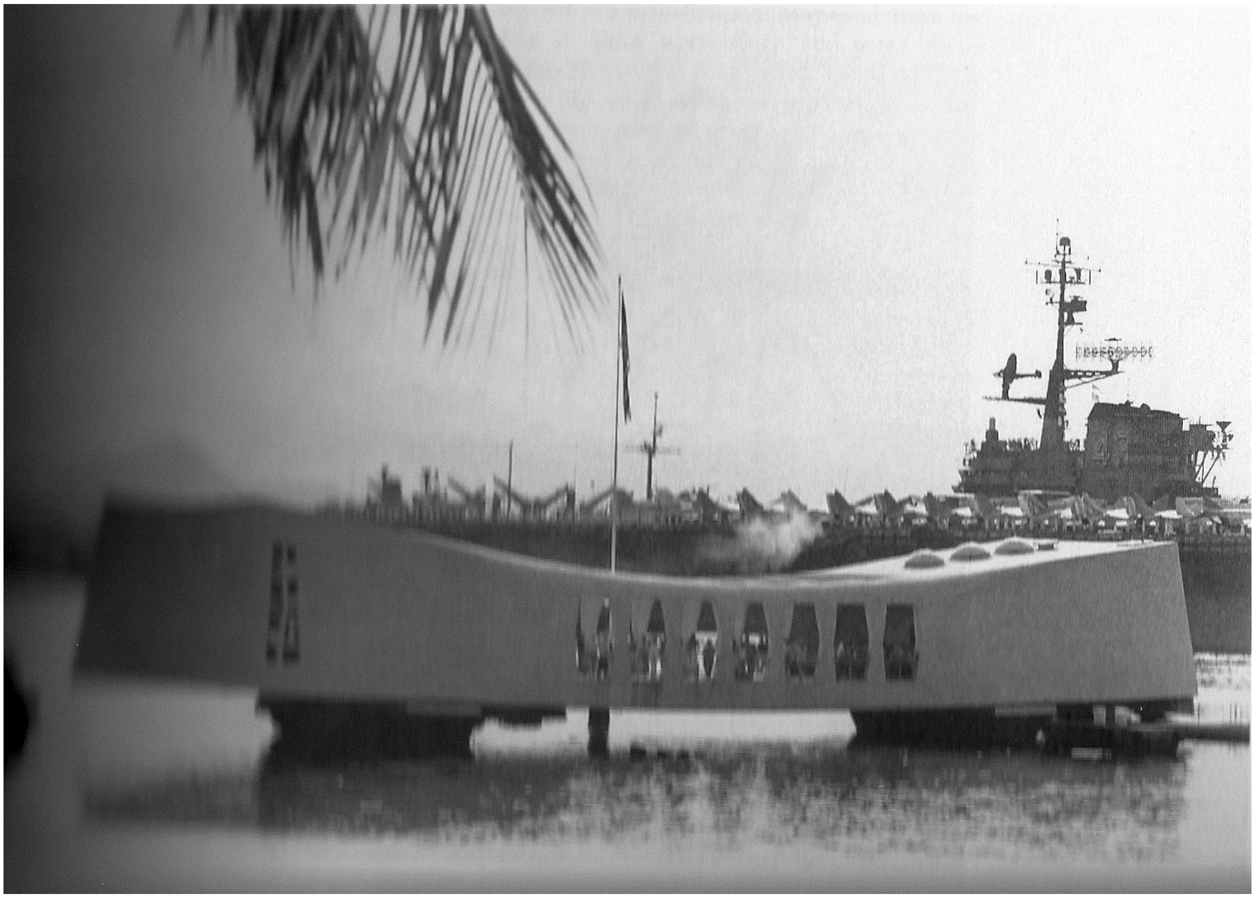
Image 8

Department of the Navy. "Man coming out of turret #3" (above), "Man after work in partially unwatered after magazines" (below). Digital Image. National Archives. http://research.archives.gov/accesswebapp/faces/showDetail?file=Item_296935.xml&loc=59 (above) http://research.archives.gov/accesswebapp/faces/showDetail?file=Item_296935.xml&loc=59 (below)

Image 9

Department of the Navy. "Salvage aerial views looking forward from just aft of turret #4". Digital Image. National Archives. http://research.archives.gov/accesswebapp/faces/showDetail?file=Item_296931.xml&loc=59

Image 10



Stillwell, Paul. "USS *Arizona* Monument". *Battleship Arizona.* Maryland: Naval Institute Press, 1991,279.

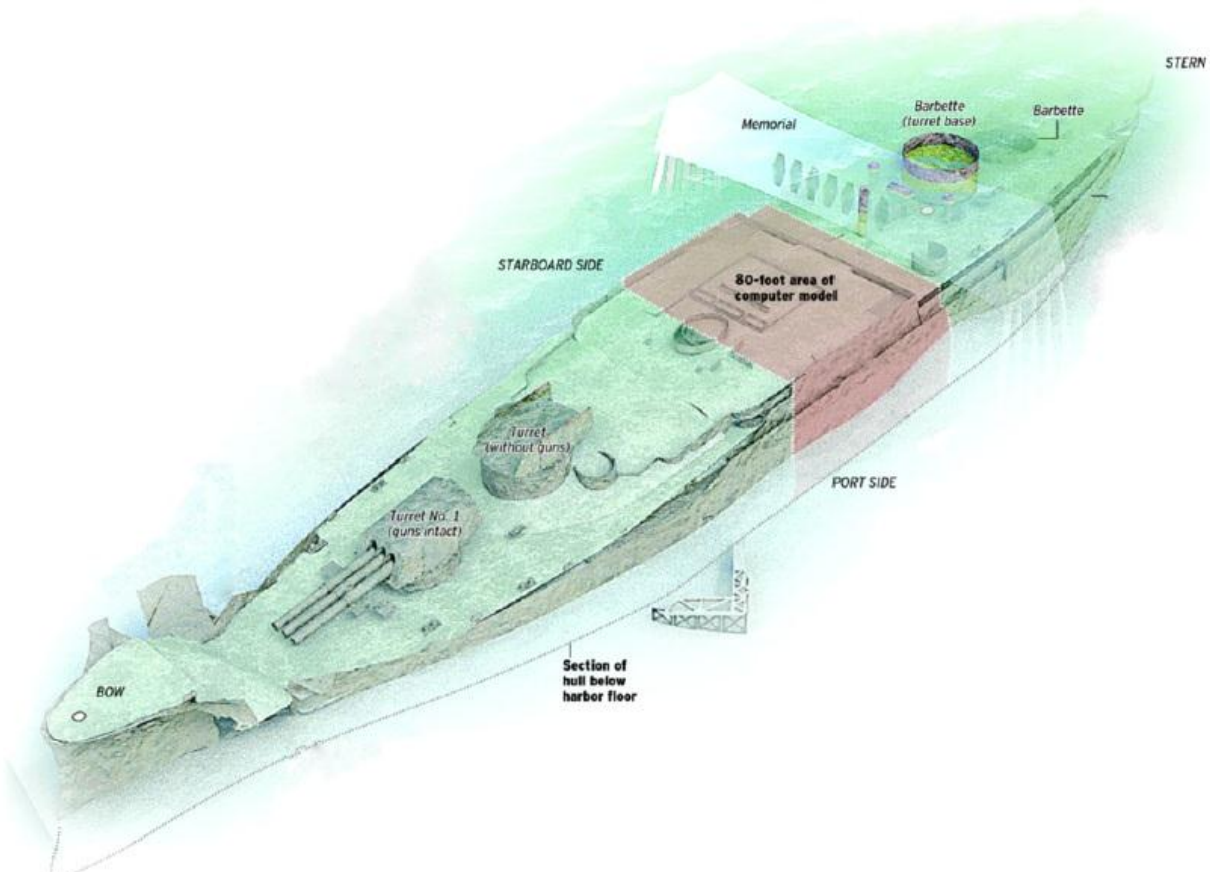
Image 11

Murphy, Larry and Matthew Russell. “Scale Drawings of USS *Arizona*”. *Introduction.* Santa Fe, New Mexico: National Park Service Submerged Resource Center, 2008.

Image 12

Russell, Matthew and Larry Murphy. "Comparison of the Original, Left, and Current GPS Monitoring Points". *Long-Term Monitoring Program: Structure, Oil, Artifacts, and Environment.* Santa Fe, New Mexico: National Park Service Submerged Resource Center, 2008.

Image 13



T. Foecke et al. “80-ft Section Chosen for FEA Model”. *Investigating Archaeological Site Formation Processes on the Battleship USS Arizona Using Finite Element Analysis.* Journal of Archaeological Science, 2010.

Image 14

Galiano, Rich. "Empty Rivet Holes in Hull Plating on the SS Mohawk". *Scuba Diving-New Jersey and Long Island New York*, 2009. http://njscuba.net/sites/site_mohawk.html.

Image 15

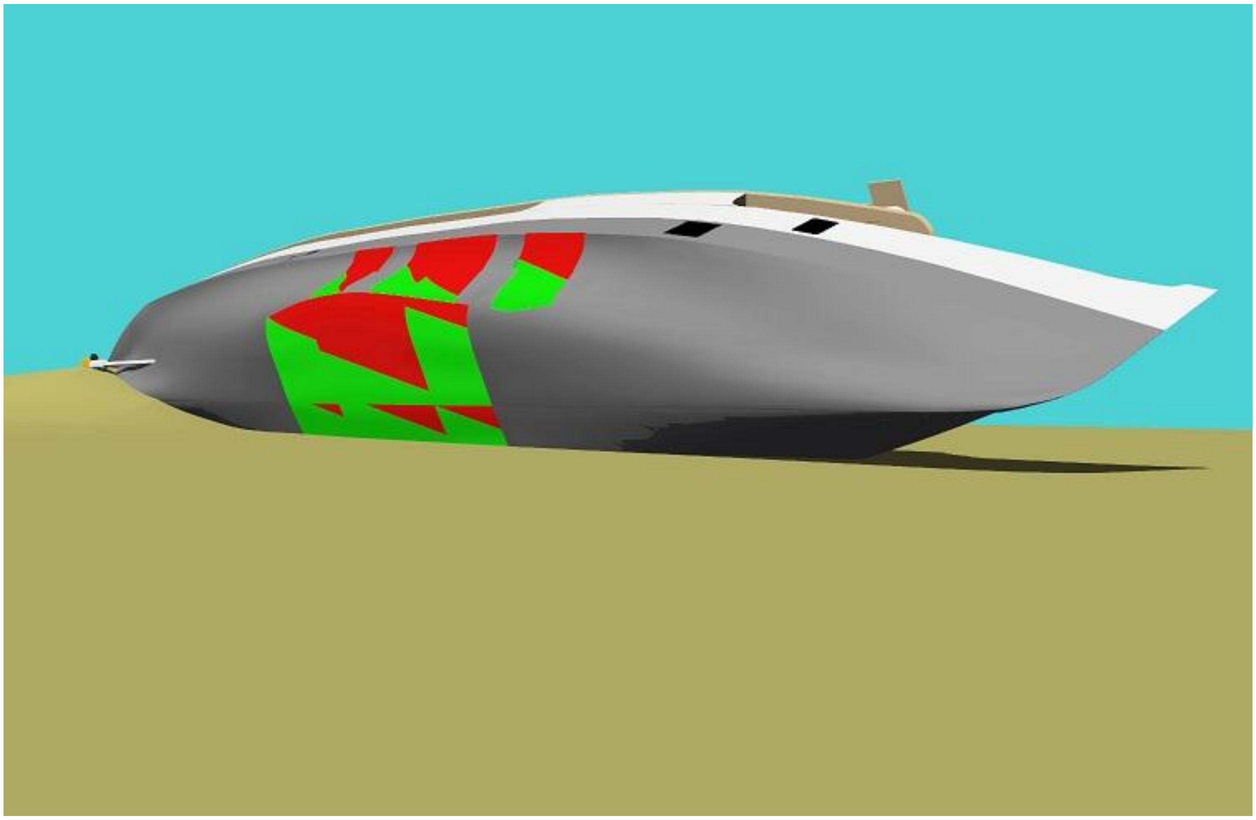
Sample Type	Corrosion Rate (mpy)
Plate A-1	2.3
Plate A-2	4
Plate A-3	5.2
Rivet Head	5.3
Rivet Shaft	2.1

Saunders, Nathan and Elliot Hamilton. "USS Arizona's Corroded Hull Plating and Rivets, Left: Plate A-1, Top: Plate A-2, Right: Plate A-3, Bottom: Rivet", above, "Corrosion Data for the USS Arizona" below. *Metallurgical and Corrosion Evaluation of the USS Arizona.* Rapid City, South Dakota: South Dakota School of Mines and Technology, 2009.

Image 16

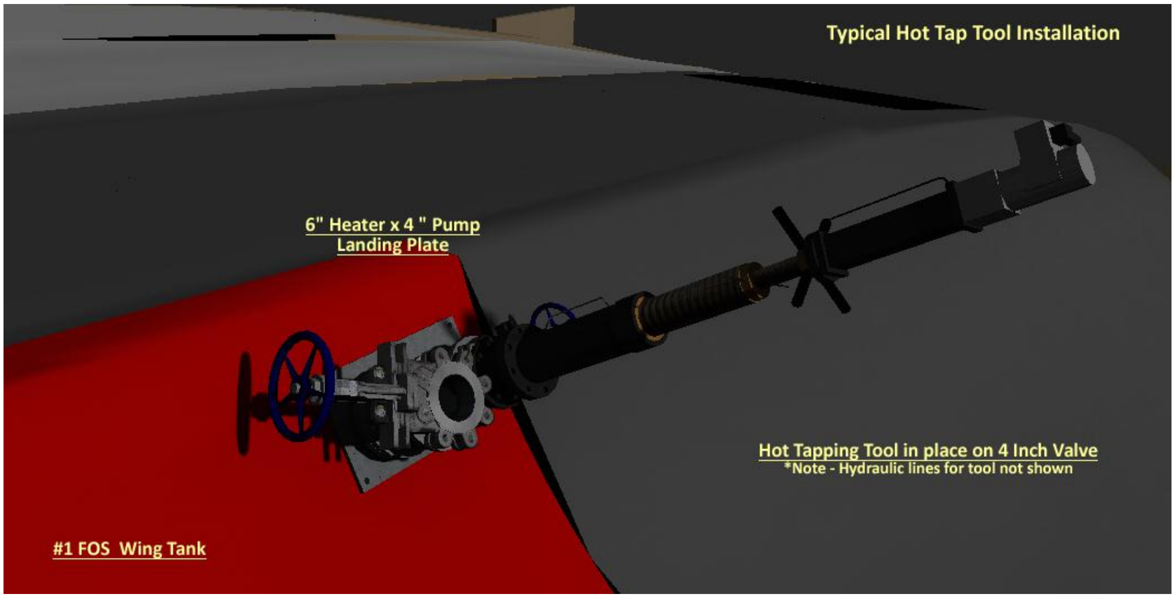
Princess Kathleen Sinks off Lena Point September 1952. 1952. Alaska State Library Historical Collection, Juneau,AK. In *Alaska Digital Archives*. Accessed December 13, 2011. http://vilda.alaska.edu/cdm4/item_viewer.php?CISOROOT=/cdmg21&CISOPTR=12832&REC=4.

Image 17



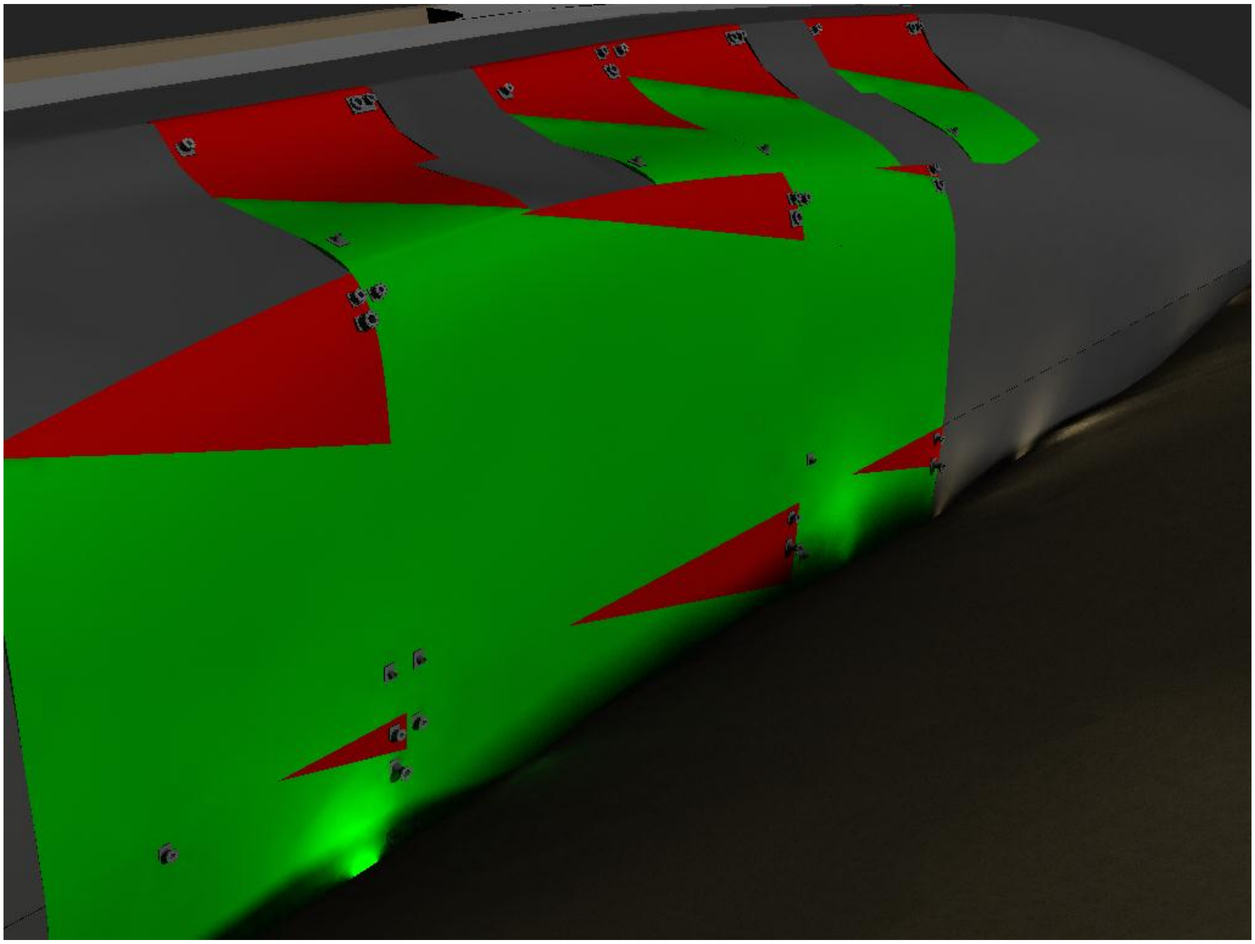
Global Diving and Salvage. "Stratified Water (Green) and Fuel (Red) on the Sunken Princess Kathleen". Author's Personal Communication.

Image 18



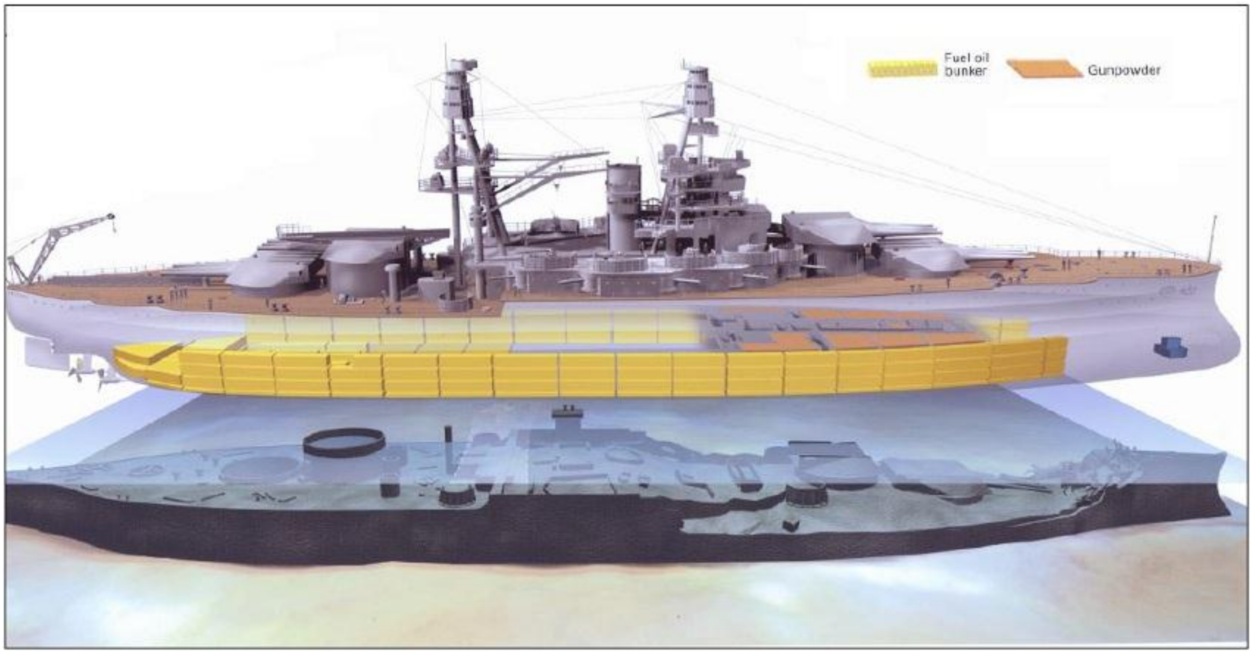
Global Diving and Salvage. "Typical Hot Tap Tool Installation". Author's Personal Communication.

Image 19



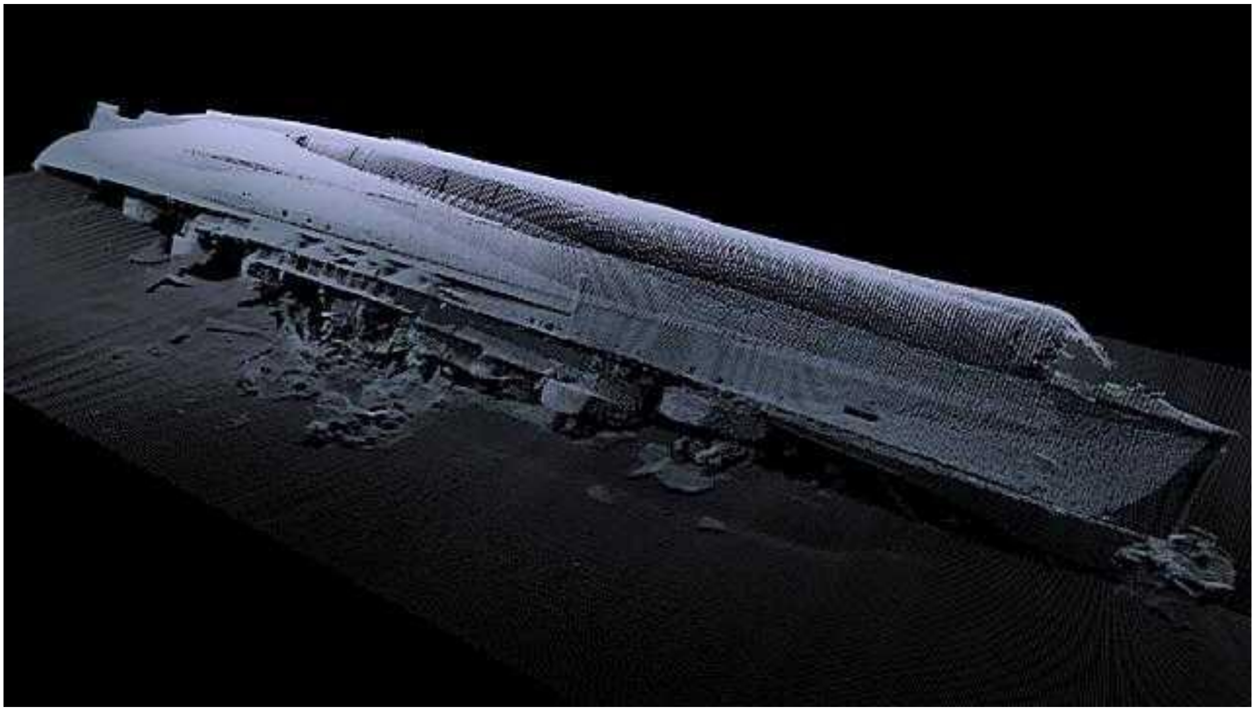
Global Diving and Salvage. “Princess Kathleen Landing Plate Locations”. Author’s Personal Communication.

Image 20



National Geographic Society. “Graphic of *Arizona* Showing Oil Bunkers and Forward Magazine Locations in Relation to Hull Damage Mapped by SRC in the 1980’s”.

Image 21



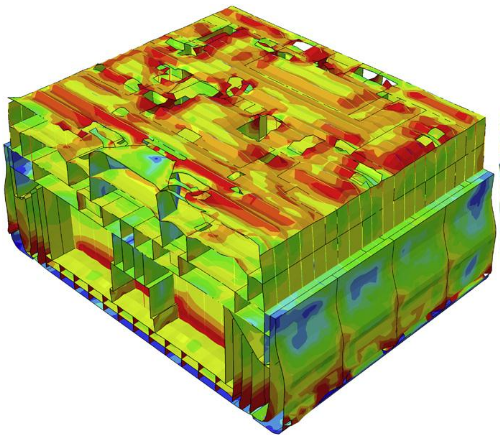
Ministry of Defense, UK. “Multi Beam Sonar Survey of HMS *Royal Oak*”.

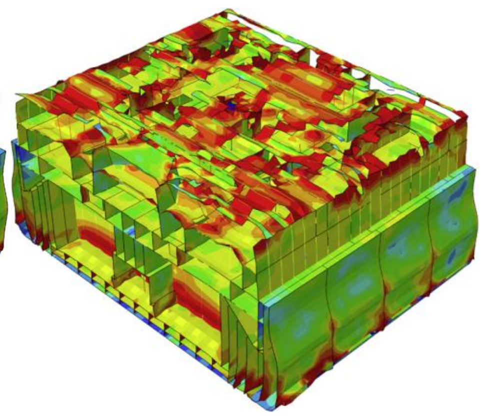
http://www.wrecksite.eu/imgBrowser.aspx?102

Image 22

"The Sinking of the USS *Mississinewa". http://www.wrecksite.eu/imgBrowser.aspx?20041.*

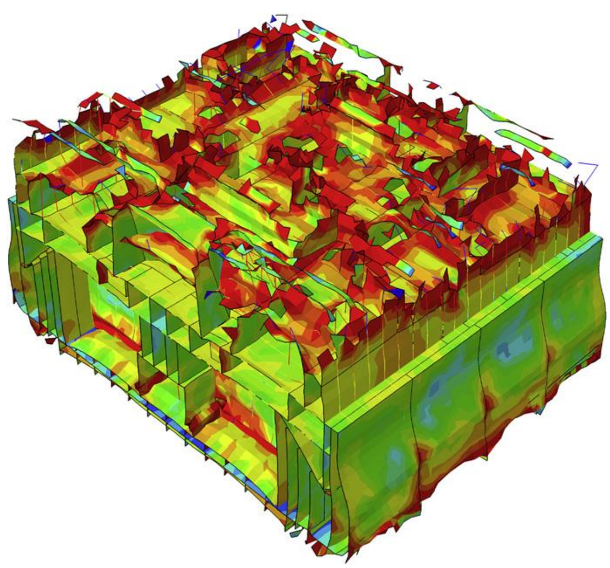
Image 23





Weight stresses after 60% thickness loss due to corrosion, approximate date=2150

Weight stresses after 70% thickness loss due to corrosion, approximate date= 2180



Weight stresses after 90% thickness loss due to corrosion, approximate date= 2240.

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