National Park Service
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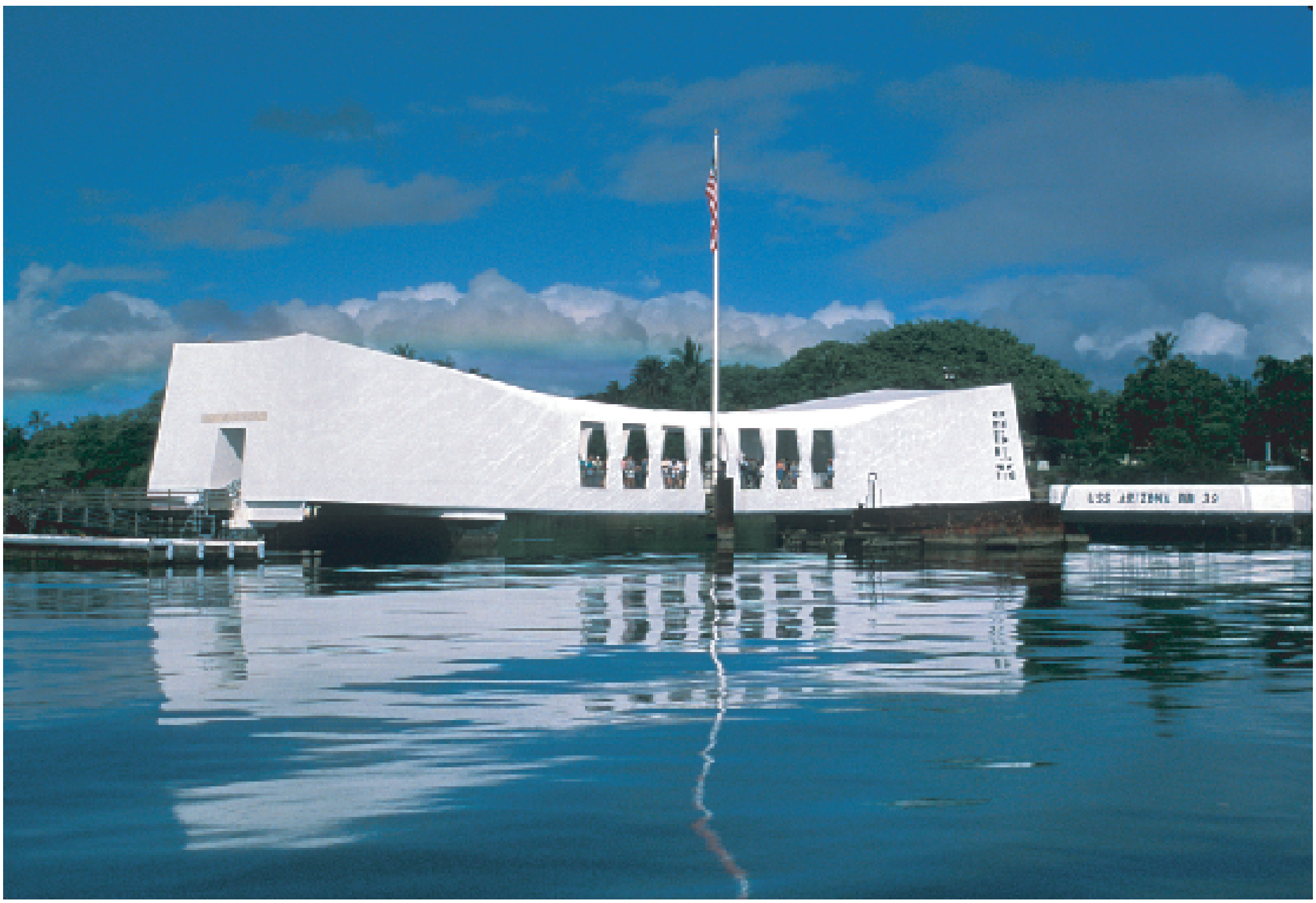
Submerged Resources Center
Santa Fe, New Mexico

USS *Arizona* Memorial

Legacy Resources Managment Fund Project No. 03-170
2003 Annual Report



Submerged Resources Center Technical Report No. 15

Long-Term Management Strategies for the USS *Arizona*: A Submerged Cultural Resource in Pearl Harbor, Hawaii

National Park Service
Submerged Resources Center and USS *Arizona* Memorial
Legacy Resources Management Fund Project No. 03-170
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USS *ARIZONA* MEMORIAL

Long-Term Management Strategies for the USS *Arizona*: A Submerged Cultural Resource in Pearl Harbor, Hawaii
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Submerged Resources Center
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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Long-Term Management Strategies for the USS *Arizona*: A Submerged Cultural Resource in Pearl Harbor, Hawaii
National Park Service
Submerged Resources Center and USS *Arizona* Memorial
Legacy Resources Management Fund Project No. 03-170
2003 Annual Report

The National Park Service's (NPS) Submerged Resources Center (SRC) received a FY03 Legacy Grant (Project No. 03-170) for research directed to understanding the nature and rate of natural processes affecting deterioration of USS *Arizona* in Pearl Harbor, Hawaii. The USS *Arizona* Long-Term Management Strategies Research Project, conducted in partnership with the USS *Arizona* Memorial (USAR), is designed to be multi-year, interdisciplinary and cumulative, with each element contributing to developing an overall management strategy designed to: 1) minimize environmental hazard from fuel oil release; and 2) provide basic research necessary to make informed management decisions for long-term preservation. This project has been designed to serve as a model because it will have direct application to preservation and management of other iron and steel historical vessels and to intervention actions for other leaking vessels. The first application of the lessons learned from the work being conducted under this research program is most likely to be applied to *Utah*, the only other vessel in Pearl Harbor remaining from the 1941 attack.

USS *Arizona*, a National Historic Landmark (NHL)—the highest level of national historic significance—is among the most recognized and visited war memorials in the nation. USS *Arizona* became a NPS unit in 1980. Currently, more than 1.5 million people annually visit the USS *Arizona* Memorial, tomb of more than 900 US sailors and the most visible warship lost in World War II (Figure 1). This ship, a national shrine and Naval memorial that remains deeply ingrained in the American consciousness, still commands an honor guard from the many capital ships that ply Pearl Harbor today, as it did during the war when it served as inspiration to Navy personnel going into battle.

The *Arizona* Legacy Project builds upon pioneering site documentation and environmental research conducted by the NPS-SRC in the 1980s. The early SRC investigations initiated *in situ* documentation and study of large, submerged steel warships both here and internationally.

The current project is designed to provide the scientific foundation for long-term preservation and management decisions for this immensely significant site. This Legacy project,

Figure 1. The USS *Arizona* Memorial, Pearl Harbor, Hawaii.

which we consider a NPS/Department of Defense partnership, builds upon the research design and fieldwork begun by SRC in 1999. Legacy Grant funding was initially provided in FY02 for what was originally designed as a three-year research project. Because funding was at a level less than requested for FY03, fieldwork and research being reported here for FY03 represents only a portion of the second year in this projected funding cycle.

To make the most cost-effective use of FY03 Legacy funds, SRC provided project principals who have been involved in *Arizona* research from its beginning, and contributed equivalent matching funds to maximize project results, in effect doubling available funds. We are also accruing significant project savings, as we did in 2002, by partnering with US Naval commands, academic institutions, commercial companies, research laboratories, professional societies and individuals willing to contribute to the research addressing the many multifaceted questions that confront managers responsible for USS *Arizona* preservation.

The primary project focus is toward developing requisite data for understanding the complex corrosion processes affecting *Arizona*'s hull, both internally and externally, and modeling and predicting the nature and rate of structural changes. Developing reasonable and effectual management alternatives and determining the most desirable actions, particularly those regarding intervention or rehabilitation, cannot be done without this scientific information.

The current project addresses another critical issue besides preservation of an important national shrine. USS *Arizona* apparently contains several hundred thousand gallons of Bunker C fuel oil, which has been slowly escaping since its loss in 1941. This oil, a potentially serious environmental hazard, is contained within the corroding hull. Catastrophic oil release, although by all indications not imminent, is ultimately inevitable.

Understanding the complex and varied hull corrosion process and modeling structural changes and oil release patterns offers the best method of developing an appropriate, sound management solution to this potential hazard. Because of the particular national importance of *Arizona*, any solution must incorporate a minimum-impact approach, or long-term site preservation can be seriously compromised. Unnecessary impairment of *Arizona*'s hull is likely to be seen by many as ultimately more problematic than oil release. Addressing the oil release problem within a site-preservation framework as incorporated within this project provides the best balance of competing social values, and it has the highest probability of success for arriving at the best and most defensible solution for both environmental and preservation issues.

Based on our experience of more than two decades of federal submerged cultural resource management research, this project, as part of a cumulative progression of multidisciplinary steps, will provide the most cost-efficient approach initially, and will provide significant cost savings in future management decisions. Dividends of this approach should also accrue to the many legacy vessels worldwide facing similar combined problems of environmental hazard and site preservation. Successful completion of the *Arizona* research and its incorporation into action with the most desirable management alternative will provide a model with global application.

2003 RESEARCH DOMAINS AND RESULTS

Research domains pursued in 2003 continue and expand the original course of research proposed at the outset of this research program. Data from these initiatives are providing a comprehensive picture of *Arizona*'s current state, and are beginning to project that understanding into the future. A major field project was conducted by NPS-SRC and USAR for three weeks in November 2003, which resulted in new data sets to be incorporated in ongoing research domains.

CORROSION ANALYSIS

Hull Sample (Coupon) Analysis

In August 2002, NPS-SRC and USAR partnered with the Naval Facilities Engineering Service Center-Ocean Construction Division, the Navy's Mobile Diving and Salvage Unit One and Titan Maritime Industries, Inc. to collect external hull plate samples ("coupons") from USS *Arizona* for electrochemical, microbiological, metallurgical and metallographic analyses. A total of eight samples were collected, four from the port side and four from the starboard side, in vertical transects from just below the upper deck to below the mudline. After removing samples, the holes were plugged, and each area but one was sealed with a pH-neutral epoxy to inhibit corrosion cell formation. The single area not completely sealed with anti-corrosion epoxy covered the surrounding metal but left the plug accessible so interior water samples could be removed should they be necessary for future analyses.

Coupons were initially sent to Rail Sciences, Inc. (RSI) Materials Engineering in Omaha, Nebraska, where Dr. Don Johnson and Dr. John Makinson made detailed thickness measurements around the circumference of each coupon under laboratory conditions. They removed a small "chord" from each sample for optical measurement of plate thickness and metallographic examination (Figure 2). This precise thickness measurement was compared to original hull thickness in each location, and a corrosion rate for that location determined.

Figure 2. Hull "coupon" with interior and exterior concretion. Note the "chord" cut from the steel sample on left.

Assuming a consistent corrosion rate since *Arizona*'s loss, the corrosion rates varied from 1.1 to 6.0 mils per year (1 mil = one thousandth of an inch). The fastest corrosion rates were obtained from the top of the hull near the surface where there is the highest level of dissolved oxygen and water movement. These hull corrosion rates can be compared to the laboratory-determined corrosion rate of unprotected mild steel, which is 4.5 mils per year. A combination of environmental variables and concretion formation are believed to account for the observed variation, a hypothesis under investigation.

After completing analysis at RSI, coupons were transferred to Dr. Tim Foecke at the National Institute of Standards and Technology (NIST) in Gaithersburg, Maryland, for additional metallographic and metallurgical testing. This analysis is on-going and will continue in FY04.

<u>Concretion Resistivity and Density Measurements</u>

During FY03, experimental work continued at University of Nebraska—Lincoln using concretion samples from USS *Arizona* provided by NPS. In addition to Legacy funds, a University of Nebraska Foundation grant supported this research. Dr. Brent Wilson and Mr. Matthew Dick conducted experiments measuring electrical resistivity and resistance of concretion to determine whether a correlation exists between those parameters and corrosion rate of *in situ* hull steel. In addition, experiments were made to measure concretion density and to determine its affect on observed hull corrosion rates. In November 2003, Dr. Don Johnson conducted more accurate field density measurements at the USS *Arizona* Memorial on concretion samples as they came out of the water. Analysis is on-going to establish a relationship between these parameters and steel corrosion rates on *Arizona*. These data will be compared with those of other researchers, including those at the Western Australian Maritime Museum.

In Situ Hull Corrosion Measurments

Immediately prior to removing hull coupons in August 2002, NPS archeologists measured corrosion potential (E_{corr}) and pH in each coupon sample location. Using the same procedure as in past field operations, SRC archeologists drilled through the concretion in proximity to the sample area measuring pH and E_{corr} at various concretion-depths. Hole depths were controlled by several depth jigs to provide uniform data. E_{corr} and pH instruments were connected to the surface by cables; the topside recorder had voice communication with the diver (Figure 3). We have found this method to produce the most consistent, reproducible results for these measurements. Immediate review by topside researchers allows anomalies or errors to be discovered and measurements retaken to ensure accuracy.

The 2002 sample locations were revisited in November 2003 to once again collect E_{corr} and pH data. This replication allows researchers to gauge the impact to the ship of removing the hull coupons and surrounding encrustation. Data collected were comparable to 2002 data from the same locations, indicating no negative impact to the ship resulted from coupon removal, and that the epoxy sealing had succeeded in preventing formation of local areas of increased corrosion during the year since coupon collection.

Ultrasonic Thickness Testing

One goal of November 2003 fieldwork was to test nondestructive hull thickness

Figure 3. NPS archeologist taking corrosion potential readings at coupon location.

measurement techniques. Because precise hull thickness is known in the location of each of the eight hull coupons, those locations were selected for ultrasonic thickness (UST) instrument testing. In December 2001, NPS-SRC tested a diver-deployed Cygnus 1 Underwater Multiple Echo Ultrasonic Digital Thickness Gauge on *Arizona*'s hull. This instrument proved to be unreliable (consistent, reproducible readings were unobtainable), even with significant surface preparation. For 2003 fieldwork, another instrument was tested. Dr. Art Leach from Krautkramer Ultrasonic Systems recommended their DMS 2 A-Scan Digital Thickness Gauge, and arranged for Mr. Jay Schraan from Inspection Technologies of Pomona, California, a Krautkramer dealer, to demonstrate their technology on *Arizona*.

In October 2003, before beginning fieldwork in Hawaii, Dr. Leach visited NIST in

Gaithersburg, Maryland, to calibrate the instrument on the hull coupons collected from *Arizona* in August 2002. This direct calibration with *Arizona* plate material allowed precise speed-of-sound measurements to be made from actual hull steel taken from the *in situ* locations to be tested. During field operations in November 2003, Jay Schraan arrived on site with the Krautkramer instrument. Our methodology was to revisit the sites of the six above-mudline hull coupons collected in August 2002. Because we know the exact hull thickness at each of these locations based on measurements made by Dr. Don Johnson and Dr. John Makinson, these locations made ideal test sites for the UST instrument.

During UST operations, NPS researchers worked underwater to prepare the hull's surface and deploy the probe, while Dr. Johnson and Mr. Schraan worked topside with the instrument's user interface (Figures 4 and 5). Surface preparation on the ship involved removing the outer encrustation and using a pneumatic grinding wheel to flatten the surface. We could not get reliable readings on the unprepared hull surface, which is mildly pitted from corrosion. Even on locations where we employed significant surface preparation, grinding the hull steel until it was shiny and smooth, the readings were not always consistent—sometimes they were accurate and other times not. For future operations in areas where the hull thickness is not already known, there would be too much doubt in the final results to be useable.

Dr. Leach and Mr. Schraan have expressed interest in working with NPS to experiment with ways to refine their instrument to make it more reliable on *Arizona*'s hull. If this instrument can be refined, it would find more wide-spread application in shallow sites and, when deployed on a ROV, in difficult access or deep sites. In addition to this opportunity, NPS-SRC and USAR will pursue other potential avenues of nondestructive thickness measurements using different technologies. Nondestructive testing is a key component of future research, necessary to determine if hull corrosion rates observed at

Figure 4. November 2003 topside ultrasonic thickness operations.

Figure 5. Deploying the ultrasonic thickness probe on *Arizona*'s hull.

the locations of hull coupons removed in August 2002 are consistent across the exposed, outer surfaces of the hull. Ideally, the appropriate technology will be deployable on a small ROV so internal measurements can be obtained.

Summary

Corrosion potential, pH and hull thickness data from *in situ* measurements were analyzed to determine the average annual corrosion rate of the submerged hull at selected sites, port and starboard, from the hull top to beneath the mudline. Based on preliminary data, corrosion rates are highest near the hull top (near the current waterline) and decrease to the lowest rates just below the mudline. Limited data at about 1½ meters below the mudline indicate that the Tafel constant is higher below the mudline than above it, indicating that oxygen availability is lower into the mud. Assuming limiting current, oxygen diffusivity in the concretion is somewhat higher than that reported for oxygen in sea water. Attenuation of the corrosion rate as a result of reduced oxygen availability across the concretion is confirmed based on voltage drop and knowledge of concretion resistivity from literature sources. X-Ray diffraction analysis of the concretion reveals that the major species is siderite ($FeCO_3$) with lower amounts of magnetite (Fe_3O_4) and calcite ($CaCO_3$). Presence of siderite and magnetite are consistent with corrosion potential/pH data superimposed on stability fields in the H_2O, Fe and CO_2 Pourbaix diagram. Chemistry and structural observations using scanning electron microscope imaging and electron dispersive spectroscopy element identification yield variable iron and calcium gradients across the concretion. Based on these analyses, the iron content of the concretion does not account for all of the iron lost from the hull. The balance may be lost to open sea water during the initial stages of corrosion and concretion formation. In addition, direct *in situ* observations confirm that iron may remain trapped in low pH solution in gaps between the hull plate and concretion. Assessment of corrosion and bacterial activity below the mudline and interior spaces continues, and they will be a focus in FY04 (Makinson et al. 2002; Johnson et al. 2003).

BASELINE ENVIRONMENTAL DATA COLLECTION

Dr. Mike Field and Dr. Curt Storlazzi from the US Geological Survey's (USGS) Pacific Science Center are continuing their collaboration with NPS-SRC and USAR researchers to analyze data from oceanographic and water-quality monitoring instruments placed on and near *Arizona*. NPS researchers and USGS scientists calibrated and deployed a SonTek wave height/current meter and a YSI multi-parameter probe on *Arizona* in November 2002. These instruments have internal memory and batteries and can be left *in situ* for up to 60 days, recording data multiple times an hour. The instruments are retrieved and downloaded, then recalibrated and deployed every 60 days by USAR staff. The data are sent to the SRC in Santa Fe, New Mexico, and the USGS in Santa Cruz, California, for compilation and on-going analysis. These instruments continue to collect baseline data including wave and current patterns around the vessel, and basic environmental parameters, such as pH, temperature, salinity, dissolved oxygen, oxygen reduction potential and conductivity. The goal is at least a two-year database to discern environmental variable patterns within Pearl Harbor.

The SonTek instrument was left in place approximately 25 m off *Arizona*'s port bow for a one-year period, from November 21, 2002 to November 20, 2003 (Figure 6). On November 20, 2003, NPS staff relocated the instrument to 25 m off *Arizona*'s starboard bow, where it will collect comparative data for another year. The YSI instrument was deployed on January 30, 2003 on *Arizona*'s main deck, amidships, just aft of the Memorial (Figure 7). It has so far collected data for a one-year period, with the exception of four months during summer 2003 due to equipment malfunction. This instrument will be left in its current location at least through summer 2004 to make up for lost data. Data from both instruments will then be synthesized by USGS and NPS scientists to determine potential effect environmental variables have on *Arizona*'s corrosion rates.

FINITE ELEMENT MODEL (FEM) DEVELOPMENT

The NPS-SRC and USAR are collaborating with Dr. Tim Foecke and Dr. Li Ma at NIST to develop a Finite Element Model (FEM) of *Arizona* to characterize hull deterioration. A FEM allows manipulation of multiple variables, such as corrosion rate and hull thickness, to

Figure 6. SonTek Triton current/wave meter off *Arizona*'s port bow.

Figure 7. NPS researcher recovering YSI multi-parameter sonde.

analyze loads and stresses on hull structure for prediction of probable collapse rate, nature and sequence and consequent impact on structures containing fuel oil. The FEM provides a fundamental tool to evaluate consequences of proposed management alternatives involving structural intervention or preservation strategies. Initial FEM development is focusing on modeling the *Arizona* hull structure in its as-built original state for a 60-ft. cross-section, amidships from frame 75 to 90 (Figure 8). This preliminary model is a necessary step to refining and testing methodologies for development of the overall model required for predicting current structural strength and, when combined with corrosion rates and other variables, will provide predictability required for evaluating timing, necessity and long-range consequences of management actions.

The next development stage will focus on incorporating structural effects of the blast and fire that sank the vessel. The final stage of FEM development will incorporate external and internal corrosion and thickness measurements. Collection of additional data and completion of this model will provide the foundation for determining most effective management alternatives, including fuel removal, containment or intervention in natural processes affecting the hull and the time scale for continued structural alterations that may require corrective action.

This work has been conducted by NIST over the course of FY02 and FY03 and will continue in FY04, as funding allows. FEM development requires significant and on-going interaction between NIST and NPS-SRC and a dynamic relationship between the two agencies. Analytical avenues evolve as additional data are collected and as the work is refined. This is pioneering research, and there is currently no standardized approach or protocol. NIST and NPS-SRC are working collaboratively to develop an integrated, multidisciplinary approach to long-term preservation research and ensure that on-going research, analysis and results complement other aspects of this project, which may require testing and revising engineering analysis techniques. Much refinement and many changes will have to be made to standard engineering practices for application to USS *Arizona*. There is currently no standardized methodology for addressing problems of the nature represented in this research

The SRC partnership with NIST represents a significant cost savings to the current project because NIST is providing matching funds in the form of laboratory analyses, supervisory personnel, equipment, administrative support and infrastructure, all of which would have otherwise been levied against available Legacy funds. A senior metallurgist at NIST is

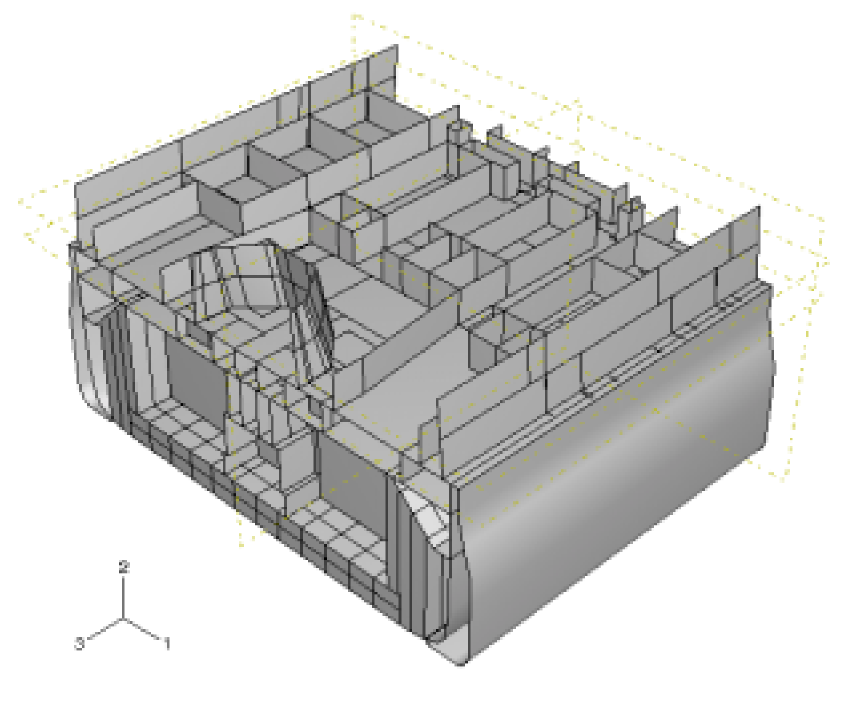

Figure 8. 60-foot midships cross-section of USS *Arizona* modelled for Finite Element Analysis.

supervising the analytical work conducted under this agreement, which will be completed using their computers, software and other equipment. The senior NIST researcher draws from experience with other historic vessels including *Titanic* and with structural failure of steel, as with the World Trade Center structural analysis. In addition, NIST will perform necessary metallurgical and metallographic sample analyses and consulting beyond the scope of this agreement with no additional charge to the project. To develop and refine such a protocol as required for historical vessels could be prohibitively expensive if it had to incorporate specific contract changes with a private firm charging hourly rates for engineers and equipment access. The success of this research endeavor solidly rests on the on-going collaboration between NIST and NPS-SRC.

OIL AND MICROBIOLOGICAL ANALYSIS

The NPS-SRC and USAR are collecting oil, sediment, water and concretion samples from *Arizona* for analysis by Dr. Pam Morris at the Medical University of South Carolina (MUSC) in support of on-going research at the site. MUSC scientists are currently developing innovative research that examines the role of microorganisms in fuel oil degradation and the aerobic biodegradation potential of microorganisms associated with the battleship's hull. In addition, collaborative research is focusing on using environmental degradation of oil trapped within different areas of *Arizona*'s hull to determine relative dating of each oil cache through determining the length of time each oil release has been in contact with seawater. This approach should provide inferential indicators about the state of deterioration and structural changes of oil bunkers that are presently inaccessible.

MUSC researchers are analyzing oil samples using mass spectrometer biomarkers, gas chromatograph analyses and other methods (Figure 9). Results of analyses may differentiate individual oil bunkers, as well as differentiate age of oil (relative to sea water exposure) in cabin overheads and being released from various locations around the battleship, which has important implications for structural analysis. They are also analyzing environmental samples (water, sediment and concretion) to identify and describe and the nature of microbiological communities present and characterize their role in the overall corrosion process affecting *Arizona*'s hull and structural integrity and develop predictions about long-term changes in the structure and environmental impact of continual or episodic oil release. Continued characterization of microbial communities active in the sediment may provide a mitigative action for oil being released into the environment. The residence time of leaked oil in the environment and the nature of its degradation provide site-specific information on long-term impact of the

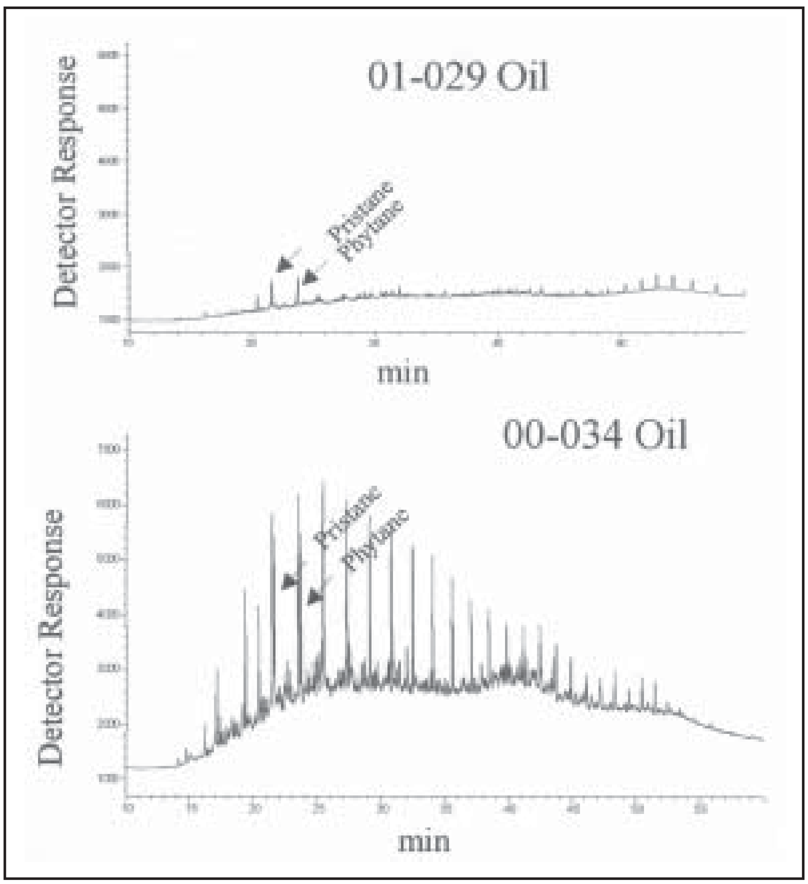

Figure 9. Gas chromatograph traces of USS *Arizona* oil samples representative for two different locations. The top oil sample shows significant weathering of the oil, most noticeably depletion of n-alkanes in comparison to the bottom sample.

present loss rate, as well as a potential increase or episodic release.

During 2003, a graduate student in MUSC's Molecular and Cellular Biology and Pathobiology Program in the Marine Biomedicine and Environmental Sciences Department, Ms. Amanda Graham, completed a Master's thesis entitled *The USS Arizona and Bunker C Fuel Oil: An Environmental Study.* Research for this study was conducted in partnership with NPS-SRC and supported in part with Legacy funds. The thesis research, using samples provided by SRC, focused on a preliminary environmental assessment of the oil leaking from the USS *Arizona* and determining if aerobic microbial degradation processes are influencing oil composition. The hypothesis of this study is that oil leaking from different areas of the ship has different chemical profiles and chemical composition and is degradable by aerobic microbial communities in surrounding sediments. Graham characterized the oil leaking from different areas of USS *Arizona* as well as the oil contamination in sediments surrounding the ship and established fuel oil biomarkers present in oil leaking from the ship and in the surrounding sediments. She also researched aerobic degradation and how these processes affect the fuel oil biomarkers. This study contributes to environmental and conservation management issues regarding the USS *Arizona* and the prediction of potential environmental impact to the surrounding area if a larger release of oil occurs (Graham 2003).

In addition to laboratory analysis, NPS-SRC researchers collected additional oil samples and bacterial samples during November 2003 fieldwork for continuing analysis at MUSC (Figure 10). These samples are currently being cultured and their DNA extracted for identification.

In addition to analysis of oil and microbes, NPS researchers measured the amount of oil escaping from the ship at several locations. This was done to quantify the leakage rate for long-term monitoring to see whether specific location oil leakage is stable or increasing. The device used for quantitative monitoring is a custom-designed oil catchment device (OCD) provided by USIA, a corporate partner. Based on qualitative observations, the primary escape point during the 1980s was a single hatch on the port side of Barbette No. 3. This point was measured in 1998 and a rate of 1.0–1.5 quarts per 24 hours was established. Since 2000, at least two additional leak points have been observed. In November 2003, NPS archeologists measured oil escaping from two primary leak points—one of which was the hatch on the starboard side of Barbette No. 3 that was measured in 1998 (Figure 11). The other was a hatch on the starboard side of Barbette No. 4. Slightly less than 1.0 quart was recorded in a 24 hour period from the hatch adjacent to Barbette No. 3, which means there has been no net increase in oil release at this point since first measured in 1998; in fact, somewhat less was recorded in 2003 than in 1998. The hatch to starboard of Barbette No. 4 had 1.3 quarts recorded during each of two 24-hour collection periods. These points will be monitored periodically, as will any new release points.

INTERIOR INVESTIGATIONS

In November 2003, VideoRay ROV interior investigation of *Arizona* continued. The goals of interior investigation are to search for access to lower decks where oil bunkers are located, visually characterize variations of interior corrosion, and to collect environmental samples and measurements to quantify interior corrosion. November fieldwork focused on the latter task. The VideoRay was equipped with a YSI multi-parameter sonde to measure pH, temperature, salinity, dissolved oxygen, oxygen reduction

Figure 10. Microbial colonies on oil in cabin overhead sampled in November 2003.

Figure 11. Oil catchment device deployed on hatch to starboard of Barbette No. 4.

potential and conductivity (Figure 12); and a GMC corrosion potential (E_{corr}) probe to collect corrosion measurements necessary for characterizing interior corrosion processes. Investigations were focused on second deck cabins accessible via open portholes and inside Barbette No. 3. Baseline measurements were collected outside each open porthole, and then a separate file was collected inside each cabin at various locations along vertical profiles. All VideoRay operations were recorded, and video time code was used to collate ROV location to specific measurements from both the YSI and GMC instruments. The VideoRay did not have the ability to carry both instruments simultaneously, so we first completed the YSI survey then conducted the GMC recording of the same interior spaces.

In general, we found that most parameters recorded with the YSI sonde were nearly the same inside the ship, at least on the second deck level, as outside: pH was 8.0–8.1, temperature about 80–81º F, salinity approximately 33.5 parts per thousand (ppt). Dissolved oxygen (DO), however, dropped dramatically upon entering the ship. Outside, DO levels were about 86–88% saturation; typical levels inside were around 65–68%, and in some instances dropped considerably lower than this. One of the more interesting observations is that interior cabin water is stratified by a subtle thermocline of about 0.5ºF—DO levels, however, change significantly across this thermocline, from nearly 70% saturation above to about 50% saturation below the thermocline. This indicates very little water movement within interior cabins, even with open portholes. Researchers are looking into what effect this has on overall interior corrosion rates and affect on microbial colonies.

Figure 12. VideoRay ROV equipped with YSI sonde entering porthole on *Arizona*'s second deck.

GMC corrosion potential measurements are still undergoing analysis. Preliminary findings indicate that interior values are 10–18 millivolts (mV) more positive than baseline readings outside each cabin. This could indicate a slightly higher corrosion rate, however there are many variables at play here, and a thorough analysis of the data is necessary before drawing any conclusions.

GPS STRUCTURAL MONITORING

Physical changes to USS *Arizona*'s hull are being monitored using a series of high-resolution GPS points established on the vessel during June 2001. SRC archeologists partnered with the US Army's 29th Engineer Battalion Survey Platoon, who provided state-of-the-art dual-frequency GPS receivers, to set a series of monitoring points across *Arizona*'s deck. Archeologists set stainless steel studs in selected locations, and then leveled a large, underwater tripod, designed by SRC, over each point. Extension poles set on top of the tripod extending above the water's surface allowed the GPS antenna to be placed precisely over the desired point. Using advanced survey techniques, the Army surveyors were able to collect points with sub-centimeter accuracy in three dimensions. The plan was to resurvey these points periodically to determine if, and how, the ship is moving, shifting and settling.

The first reoccupation of the GPS monitoring points was scheduled for November 2003. In the intervening two-year period, the NPS acquired the necessary instruments to complete the survey in-house. Mr. Tim Smith from the NPS-GPS Program and Mr. Mark Duffy from Assateague Island National Seashore provided instruments and expertise to complete the operation. The first problem encountered was that most of the stainless steel studs, which were encased in epoxy, had corroded away. The epoxy did not prevent electrolytic corrosion of the stainless steel imbedded in the mild steel of the deck plates. Each point was reoccupied as best as possible, but we made the decision that new points not subject to corrosion must be established (Figure 13 and Table 1). PVC was used, and each new point was established adjacent to the original point. Each of these new points was then surveyed and will become the permanent monitoring points (Figure 14).

Although the accuracy of each point was mathematically calculated to about 0.5 cm, it became clear that a more conservative threshold of change should be applied to future monitoring relocations. Because of environmental conditions and differences in equipment and stadia variations, we determined a more realistic threshold was 10 cm. Errors of up to 10 cm could be caused by instrument error, set-up

Figure 13. GPS tripod set on a 2001 monitoring point.

Table 1. GPS monitoring points.

June 2001 GPS monitoring point	Nov. 2003 re-survey of monitoring points	Horizontal Difference (cm)	Vertical Difference (cm)
USAR-SP-001_01	USAR-SP-001A_01	3.2	4.3
USAR-SP-002_01	USAR-SP-002A_01	1.4	2.4
USAR-SP-003_01	USAR-SP-003A_01	2.7	4.3
USAR-SP-004_01	USAR-SP-004A_01	2.1	0.2
USAR-SP-005_01	USAR-SP-005A_01	3.9	0.4
USAR-SP-006_01	USAR-SP-006A_01	10.0	25.6
USAR-SP-007_01	USAR-SP-007A_01	17.3	20.2
USAR-SP-008_01	USAR-SP-008A_01	n/a	n/a

error, or most likely, nearly imperceptible antenna movement caused by water movement. Consequently, any observed change that is less than 10 cm cannot be reliably attributed to actual movement of the ship; however, corroborative evidence would be sought for any level of change.

GEOLOGICAL ANALYSIS

A key component to the overall USS *Arizona* and *Utah* research strategy is an investigation of the geological substrate surrounding and beneath the hull. To be accurate, future predictions regarding structural stability, such as those produced from the FEM analysis, and interpretation of GPS monitoring-point movement must control for geological support variables. Hull stability is directly affected by the stability of sediments supporting *Arizona*, so seismic survey data will be combined with detailed core analysis to provide a comprehensive picture of the geologic substrate surrounding and beneath *Arizona*'s hull. An NPS/USGS team conducted subbottom profiler survey in August 2002. Based on that data, four locations around USS *Arizona* were chosen for geological coring.

Geological Core Collection

In November 2003, NPS-SRC collaborated with Dr. Rob Kayen and Mr. Brad Carkin from the USGS's Western Region Coastal and Marine Geology Program. The joint NPS/USGS team worked with an environmental contractor from Honolulu, Ernest K. Hirata & Associates, Inc. to collect geological cores from around *Arizona* (Figure 15). Because of field exigencies, primarily encountering very hard substrate in the first boring, only three of the four planned cores were collected. The three borings were drilled to depths ranging from 15.2 to 21.3 m below the harbor bottom. The borings were drilled using portable drilling equipment mounted on a temporary barge. Continuous sampling was performed from the harbor bottom down to the maximum depths drilled in all borings (Hirata 2003).

The recovered cores will be split longitudinally and their stratigraphy described. Sub-samples of the cores will be taken and analyzed for grain size according to American Society for Testing and Materials (ASTM) protocol ASTM D-422-63 (Standard Test Method for Particle-Size Analysis of Soils). In addition, the core sediments will be analyzed for

Figure 14. NPS archeologist installing new GPS monitoring point (right) adjacent to the old point (left).

Figure 15. Geologial coring operations, November 2003.

structural characteristics according to either ASTM D2166-00 (Standard Test Method for Unconfined Compressive Strength of Cohesive Soil) or ASTM D2850-95 (Standard Test Method for Unconsolidated-Undrained Triaxial Compression Test on Cohesive Soils). Lead-210 (^{210}Pb) and/or Cesium-137 (^{137}Cs) radiometric sediment dating will also be completed to determine net sedimentation rate and variation. In addition to directly measurable data on the stability of geological strata surrounding USS *Arizona*, these cores will also provide stratigraphic correlation for precise sub-bottom profile record interpretation.

GEOGRAPHIC INFORMATION SYSTEM DEVELOPMENT

Geographic Information Systems (GIS) allow researchers to incorporate different types of data such as maps, plans, graphs, video and photographs into a single, cumulative, spatially referenced database for rapid display and manipulation. Primary electronic data are being consolidated into a single GIS database, including existing plans and technical drawings, photographs and results from archeological fieldwork.

During summer and fall 2003, NPS-SRC contracted with Northrop-Grumman Mission Systems (NGMS) of Lakewood, Colorado, to begin development of a GIS project that could incorporate the approximately 8,000 individual ships' plans we have collected and scanned. The first step was to digitize base maps of each of *Arizona*'s deck levels. Simultaneously, NGMS created a geodatabase of USS *Arizona* that includes all information for each cabin and space available on the plans—each object, space or cabin is a digitally separate entity with all attributes linked to it through the geodatabase. Using these base maps and geodatabase, scanned ship's plans can be "linked" to their appropriate object or location on the ship. Next, the NGMS team "developed an ArcIMS website to serve annotated vector polygon layers of the USS *Arizona* that logically track associations to a database of digital reference imagery. The web map is currently a prototype as it was developed with limited hours and remaining budget from the USS *Arizona* geodatabase creation" from FY03 Legacy funding. This spatial web portal prototype is a useful proof-of-concept that demonstrates imagery linked to features on the decks of the USS *Arizona* as well as image search and display functionality (Figure 16) (Brown 2003). The NGMS report goes on to describe in more detail the prototype created:

> <u>Map Display</u>
>
> The web site currently provides functionality to view all 8 layers of the USS Arizona, query for specific features in each layer, identify features in each layer (name and description fields are most useful), turn layers on and provides for standard interactive map tools such as pan and zoom. Each layer is rendered with a 30% transparency so that deck features below the current deck may be seen "through" the top most deck that is displayed. The decks are accurately ordered in the table of contents from top to bottom. All standard web map functions are included in this HTML map service.
>
> <u>Document Management</u>
>
> The prototype website has two custom functions that allow scanned engineering drawings to be viewed through the web interface. These tools are located on the left frame under the title "Access Images" and are names: *by Feature* and *by Query*. The first tool enables the user to select a feature on a deck of the ship

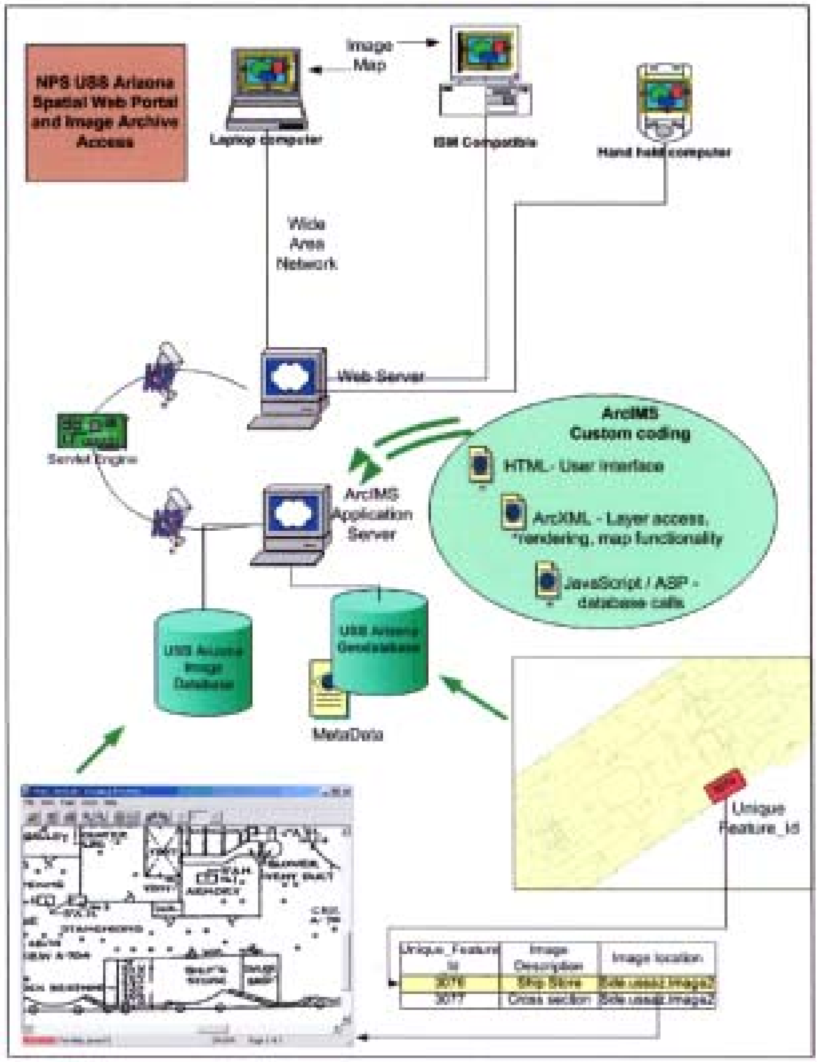

Figure 16. USS *Arizona* web portal system architecture schematic.

and query the SQL Server 2000 Database for images associated to that feature. The system architecture schematic details this process.

If multiple images are related to that one feature (room or gun turret for example) then a list of images is returned with their description. The user selects one of the images and it opens a new browser window to view the image. The prototype utilizes Lizard Tech's loss-less image compression format for image storage and viewing. A Lizard Tech browser plug-in is required for viewing the images in a standard web browser. A link to the download site is provided on the interface.

The second custom tool (*Access Images by Query*) queries the database directly to produce a unique list of image themes. The user chooses a theme and is returned a subsequent list of all the images and their descriptions that fall under that theme. As the user selects an image, a new browser window is spawned to display the image.

A good deal of time was spent creating metadata for each image in the database. This metadata is what enables the document management process to work. Each image was described and given a subject or "theme" as well as linked to specific features in the 8 levels of the geodatabase by a unique feature-id (key field). Two tables were created to enable this process (Brown 2003).

The next step in the process is to refine the project and database, eventually incorporating all scanned plans from *Arizona*, and porting the project to an NPS network, which would allow mobile and remote access to the plans by various researchers and the public.

CONCLUSIONS

The present USS *Arizona* project builds upon earlier research conducted on the site by the NPS-SRC. The current project was initiated in 1998, when SRC began developing a multdisciplinary research design intended to be a comprehensive analysis of *Arizona*'s corrosion and deterioration, providing information for its long-term preservation and to minimize risk to the environment from oil release. The current NPS/Department of Defense partnership has allowed the research to move forward in a substantial way through the Legacy Resources Management Fund. This continuing project will ultimately allow managers to make informed decisions about *Arizona*'s future based on solid scientific evidence. Fieldwork and data analysis described in the 2002–2003 Legacy Project Proposal is progressing as planned. Work on additional products, such as an interim report, video report, professional seminar and analysis of remote monitoring technology is on-going and will be completed should funding levels allow continuation of the planned research program.

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