Long-Term Management Strategies for the USS *Arizona*: A Submerged Cultural Resource in Pearl Harbor, Hawaii
National Park Service
Submerged Resources Center
Legacy Resources Management Fund Project No. 02-170
2002 Annual Report

The National Park Service's Submerged Resources Center (SRC) received a FY02 Legacy Grant (Project No. 02-170) for research directed to understanding the nature and rate of natural processes affecting the deterioration of the USS *Arizona* in Pearl Harbor, Hawaii. The USS *Arizona* Long-Term Management Strategies Research Project 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 the basic research required 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 iron and steel historical vessels and to intervention actions for other leaking vessels.

The 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 National Park 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. 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 USS *Arizona* Memorial, Pearl Harbor, Hawaii

The *Arizona* Legacy Project builds upon pioneering site documentation and environmental research led by the National Park Service's Submerged Cultural Resources Unit (renamed Submerged Resources Center (SRC)) in the 1980s. The project is designed to provide a foundation for long-term preservation and management of this immensely significant site. The

early SRC investigations initiated *in situ* documentation and study of large, submerged steel warships both here and internationally. This Legacy project, seen as a Department of Defense-National Park Service partnership, contributes directly to the current research design, which SRC developed and commenced fieldwork in 1999.

To make the best use of Legacy funds, SRC provided project principals who have been involved in *Arizona* research from the beginning and equivalent matching funds to maximize project cost efficiency, in effect doubling available funds. We are also accruing project savings, as we have done in the past, by partnering with Navy and Army units, academic institutions, commercial companies, research laboratories, professional societies and individuals in addressing the many multifaceted questions that confront managers responsible for USS *Arizona* preservation and minimizing environmental risk.

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 information. This Legacy Project research is an important step in obtaining necessary scientific information upon which sound management decisions will be made.

This project addresses another important issue besides preservation of an important national shrine. USS *Arizona* apparently contains several hundred thousand gallons of 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 a 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 will be compromised. Unnecessary impairment of *Arizona*'s hull is likely to be seen by many as 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 multi-disciplinary investigation steps, will provide the most cost-efficient approach initially, and it will provide significant cost savings in the future. Dividends of this approach will 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 within the most desirable management alternative will provide a model with global application wherever Legacy vessels lie. A couple examples of similar problems of oil release from historic vessels that have come to our attention in the last several months can be found in the Pacific with USS *Mississiwina* in Ulithi Harbor, Yap and *Chehalis* in American Samoa.

Research Initiatives:

I. Corrosion Analysis

In Situ Hull Corrosion Measurments

In situ corrosion measurements have been taken systematically along *Arizona*'s hull, including pH and corrosion potential (E_{corr}). At selected stations on the vessel, SRC archeologists working the metallurgists from the University of Nebraska, Lincoln drilled through the concretion, measuring pH and E_{corr} at various concretion-depths. Hole depths were controlled by several depth jigs to provide uniform data. Multiple samples were drilled in a vertical transect at each station at varying water depths to characterize how the corrosion process changes with water depth and concretion thickness. E_{corr} and pH instruments were read out to the surface by cables; the topside recorder had voice communication with the diver. In addition to pH and E_{corr}, other parameters, such as dissolved oxygen, were also recorded and samples collected for analysis by a microbiologist to determine the role of microbes in the overall corrosion process.

University of Nebraska metallurgist drilling through *Arizona* encrustation

NPS archeologist taking *in situ* corrosion measurments

Hull Sample ("Coupon") Analysis

In August 2002, NPS-SRC 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. MDSU surface-supplied divers removed each coupon from prescribed locations using a four-inch proprietary hydraulic-powered hole saw developed by Titan. This hole saw does not utilize a pilot hole, which compromises sample integrity. The coupons were removed from external,

vertical hull locations marked by SRC archeologists. For analytic purposes, each sample had to be collected with concretion intact on both sides of the coupon. Eight coupons were collected, four on the port side and four on the starboard side, in vertical transects located at Frame 75. On each side, one sample was taken at the Upper Deck level, near the water line; from the Second Deck level, above the torpedo blister; from the Third Deck level, in the torpedo blister; and from the First Platform level, in the torpedo blister and below the mud line. Ship plans were consulted for each location to ensure no compartments potentially containing oil would be penetrated. However, as a caution, a half-inch hole was drilled near the sample location with a drill-tap that could be easily plugged should oil be encountered.

Before beginning work, NPS archeologists measured a variety of corrosion-related parameters, such as corrosion potential and pH, in each coupon location above the mud line. During drilling operations, NPS archeologists took the same measurements at each coupon location below the mud line after the divers removed sediment. Internal water was sampled immediately upon collection of the sample.

MDSU diver collecting *Arizona* hull sample

Hull sample with intact interior and exterior encrustation

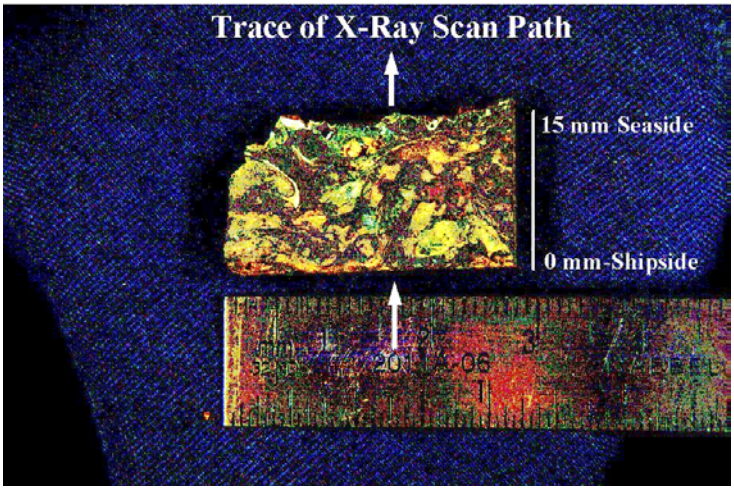
The drilling operations were directed, monitored, filmed and photographed in-water by SRC personnel using scuba equipment. After removal of each coupon, the holes were sealed with an expandable plug, and the plug and magnetic footprint for the hole saw were covered with epoxy to minimize future corrosion in those locations. Sample analysis is on going.

X-ray Diffraction and Scanning Electron Microscope Analysis of Concretion

A 5.5 cm (2.2 inch) diameter section of concretion from the USS *Arizona* was collected by using an air-powered hole saw. This sample was used for analysis to provide information to aid in the understanding of the kinetics and mechanisms of the corrosion process. The sample was investigated by X-ray diffraction (XRD) and Environmental scanning electron microscopy (ESEM). The concretion was sectioned on a diamond saw using water containing a three percent TRIMSOL as a lubricant.

X-Ray Diffraction:

Robert De Angelis from the Air Force Research Laboratory, Eglin Air Force Base, conducted the X-ray diffraction. The thin slice sectioned from the concretion was mounted in a Seimens X-ray diffractometer. The diffractometer was outfitted with a tube containing a copper anode and a graphite beam diffracted beam monochromator. The beam size at sixty degrees two theta was two millimeters by one centimeter. X-Ray patterns were collected over the angular range of 10 to 80 degrees two theta. A measurement was made every millimeter through the thickness of the specimen. The various phases present in the XRD patterns were determined with the aid of Seimens search-match software. Excellent fits to the observed XRD patterns were obtained with the combination of three phases: aragonite, siderite and magnetite. It is apparent that the siderite was the major component in the concretion in the 13 mm of thickness near the ship surface. Aragonite, which was almost absent in the first 13 mm near to the ship, exists in the two millimeters of the concretion to the ocean-side. These were the two major crystalline components found in the concretion. Magnetite was also observed to be present in the concretion. The distribution of magnetite was uniformly low in concentration through the 13-mm thickness from the ship's surface. The magnetite concentration increased in the last two millimeters of thickness.



Scanning Electron Microscope**:**

The identical slice of concretion that was employed in the XRD portion of this investigation was also used to for ESEM observation. Dr. Richard Schalek, Research Specialist in the Composite Materials and Structures Center at Michigan State University, made the ESEM observations. He selected eleven positions on the cross-section of the concretion slice to probe with the electron beam. The data collected consisted of structural images collected from back-scattered electrons and chemical images of the same areas collected from the florescence radiation of the particular element. The elements imaged were Fe, Ca, Ta, Al, Si, Br, O, Cl, C and S. The compositions at the eleven positions were calculated from the total florescence X-ray spectrum obtained from each of the eleven-probe position. The initial seven of the eleven probe positions tracked the x-ray path and were at the following distances from shipside; 1-0.8 mm, 2-5.4 mm, 3-2.9 mm, 4-6.9 mm, 5-8.3 mm, 6-9.5 mm and 7-10.7 mm. The last four probe positions were selected at interesting features in the structure of the concretion. These four probe positions were at the following distances from shipside, 8-13.5 mm, 9-10.4 mm, 10-8.7 mm and

11-10.7 mm. Compositional scans were also made along lines about 250 um in length to document the inhomogeneous structural characteristics of the concretion.

II. Baseline Environmental Data Collection

Dr. Mike Field and Dr. Curt Storlazzi from the US Geological Survey's Pacific Science Center are assisting NPS-SRC researchers to analyze data from oceanographic and water-quality monitoring instruments placed on *Arizona*. These instruments are collecting baseline data including wind, wave and current patterns around the vessel, and basic environmental parameters, such as pH, temperature, salinity, dissolved oxygen, oxygen reduction potential and conductivity. USGS and NPS researchers will analyze these data to determine how they affect overall corrosion rates on *Arizona*.

NPS-SRC and USS *Arizona* Memorial researchers collaborated with USGS scientists to calibrate and deploy 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 at a time, recording data several times an hour. The instruments will be retrieved and downloaded, then re-calibrated and deployed every 60 days by Memorial staff. The data will be sent to the SRC in Santa Fe, NM and the USGS in Santa Cruz, CA for analysis.

III. Finite Element Model (FEM) Development

The SRC is collaborating with researchers at the National Institute of Standards and Technology (NIST) to conduct this modeling and analysis. Collaborative research with NIST will be directed at evaluating possible engineering models and developing a preliminary model, likely a Finite Element Model (FEM) characterizing USS *Arizona* hull deterioration. This type of model will allow manipulation of variables, such as corrosion rate and hull thickness, to analyze loads and stresses on hull structure to predict collapse rate, nature and sequence and their impact on structures containing fuel oil, in addition to serving as the principal evaluation tool for alternative management actions. Initial efforts will focus on modeling the Arizona hull structure in its as-built original state. This preliminary model is fundamental to understanding the vessel's present condition and projecting its future condition, and the rate and nature of deterioration. This assessment must be completed prior to development of the overall model required for predicting current structural strength and, when combined with corrosion rates, will provide predictability required for evaluating future management actions.

Next, work will focus on incorporating the structural effects of the blast and fire that sank the vessel. The final stage 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 will be conducted by NIST over the course of FY02 and FY03 and will require significant and on-going interaction between NIST and NPS-SRC during that time. There will be a dynamic relationship between the two agencies, and analytical avenues will 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 will work 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 on other structures.

This partnership with NIST represents a significant cost savings to the 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. Much refinement and many changes will have to be made to standard engineering practices for application to the USS *Arizona*. There is no currently no standardized methodology for addressing problems of the nature represented in this research. To develop and refine a protocol would be prohibitively expensive if it had to incorporate specific contract changes with a private firm. The success of this research effort solidly rests on the on-going collaboration between NIST and NPS-SRC. A senior metallurgist at NIST will supervise the analytical work conducted under this agreement, which will be completed at their facility in Gaithersburg, Maryland, using their computers, software and other equipment. In addition, they will perform necessary metallurgical and metallographic sample analyses and consulting beyond the scope of this agreement at no charge to the NPS.

IV. Oil and Microbiological Analysis (MUSC)

Scientists from the Medical University of South Carolina (MUSC) are analyzing oil leaking from the hull and trapped in interior spaces of *Arizona* to determine internal leak-points as indicators of interior structural collapse. Analysis of oil samples may determine if different "reservoirs" of oil have been exposed to the environment for different lengths of time, and therefore may have come from different locations within the lower hull. In addition, SRC archeologists mapped the extent of oil present in the overheads of various cabins, which may give an indication of whether oil is being released from below decks from a single source or multiple sources, which indirectly gives evidence of interior structural collapse.

The NPS-SRC is collecting oil, sediment, water, and concretion samples from *Arizona* that is being analyzed by 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, which may indicate the state deterioration and structural changes of below decks oil bunkers.

MUSC researchers are analyzing oil samples provided by NPS-SRC using mass spectrometer biomarkers, gas chromatograph analyses and other methods. 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. 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

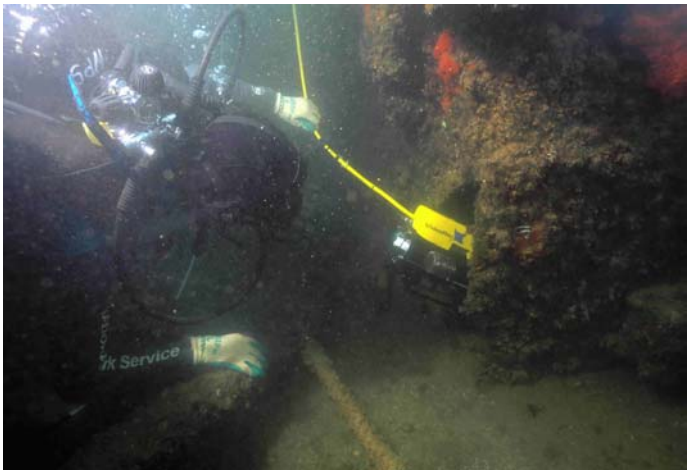
release. Continued characterization of microbial communities active in the sediment may provide a mitigative action for oil being released into the environment.

Interior cabin with oil pooled in the overhead. A microbial colony is growing on the oil.

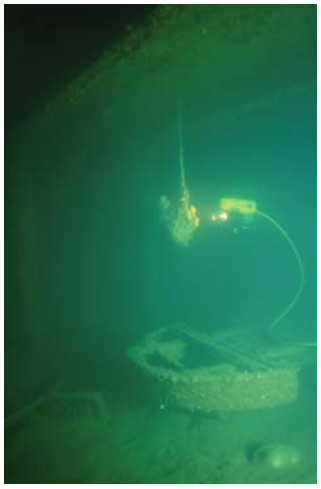
NPS archeologists collecting oil from cabin overheads.

V. Interior Investigations

In September 2000 and June 2001, the NPS partnered with VideoRay, Inc., manufacturers of a miniature remotely operated vehicle (ROV), to conduct internal investigations of *Arizona*. The VideoRay is a practical alternative to systematic interior investigation being done by divers, which removes entrapment issues and preserves the site as a war grave. The VideoRay ROV can investigate interior spaces not accessible to divers or larger ROVs.



NPS archeologist deploying the VideoRay ROV



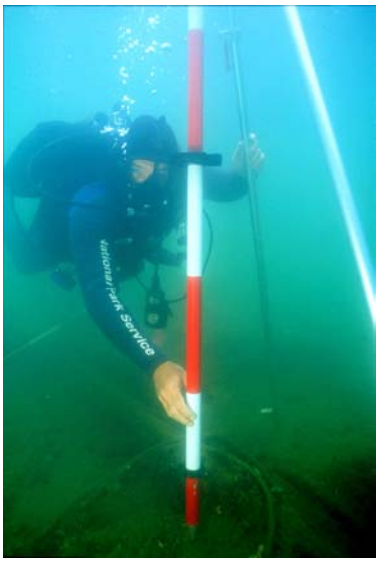
VideoRay ROV investigating the Admiral's cabin

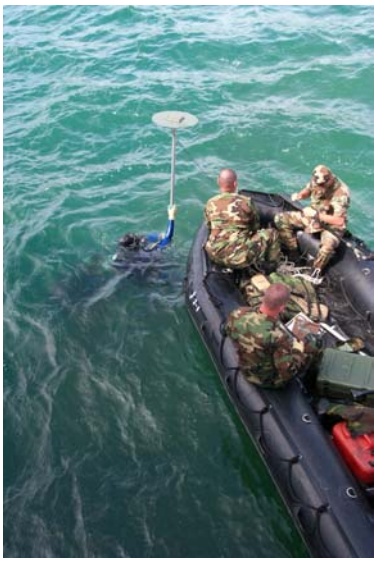
The goals of the interior investigation are to visually search for access to lower decks where oil bunkers are located and to collect environmental samples and measurements to

determine interior corrosion. The VideoRay was equipped with a Cygnus ultrasonic thickness gauge in June 2001 to measure interior bulkhead thicknesses, which can be compared to original thickness to give an indication of corrosion. In addition, the VideoRay can be equipped with a YSI Multi-parameter probe to measure pH, temperature, salinity, dissolved oxygen, oxygen reduction potential and conductivity; and corrosion potential probes to collect the full array of corrosion measurements necessary for characterizing interior corrosion processes. Testing of the VideoRay for application to USS *Arizona* research proved successful, and it has been incorporated as a key research element. VideoRay donated a base-level model to which additional instrumentation was added for to continue interior investigations.

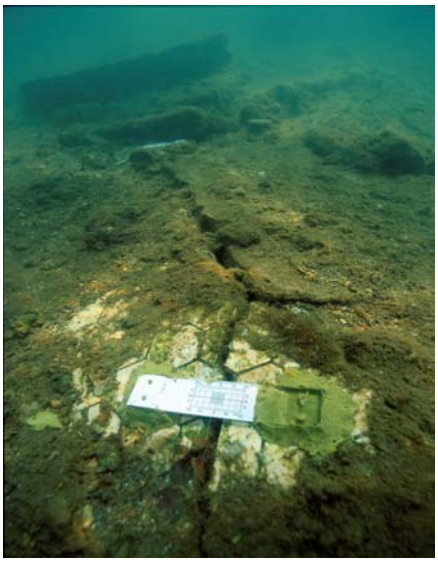
VI. GPS Structural Monitoring

Physical changes to USS *Arizona*'s hull are being monitored using a series of high-resolution GPS points collected 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 the *Arizona*. Archeologists set stainless steel studs in selected locations, 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. These points will be re-surveyed periodically to determine if, and how, the ship is moving, shifting, and settling. In addition to these high-tech methods, structural changes are being monitored using a series of crack monitors normally employed in measuring how cracks are widening on historic building walls. These plastic monitors were affixed over numerous cracks in areas where *Arizona*'s hull seems to be experiencing the most change. The crack monitors are checked periodically to see if the cracks are widening or shifting.





NPS archeologists collecting GPS data with a US Army survey platoon



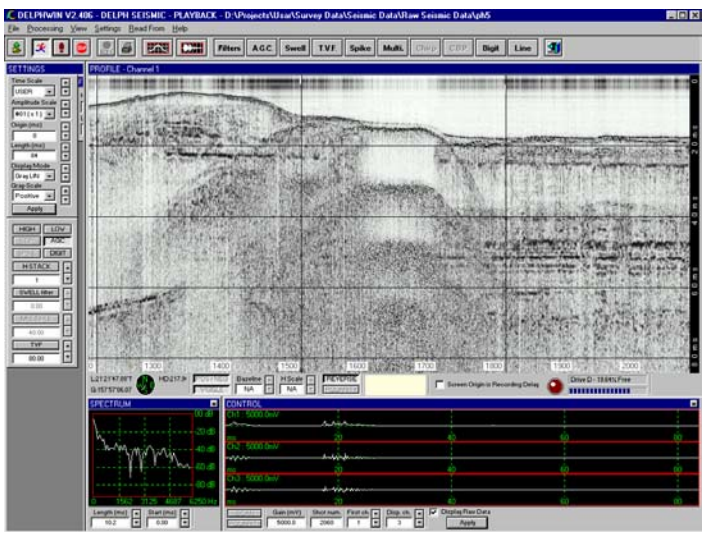
Crack monitors on *Arizona*'s deck

VII. Geological Analysis

A key component to the overall USS *Arizona* and *Utah* research strategy is a geophysical 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.

Sub-Bottom Profiler Survey

In August 2002, NPS-SRC collaborated with Dr. Mike Field, Mr. Patrick Hart and Mr. Larry Kooker from the US Geological Survey's Western Region Coastal and Marine Geology Program. The joint USGS/NPS team conducted sub-bottom profiler data acquisition in areas of Pearl Harbor surrounding *Arizona* and *Utah*. Analysis of data from this survey is on-going and being conducted by USGS.



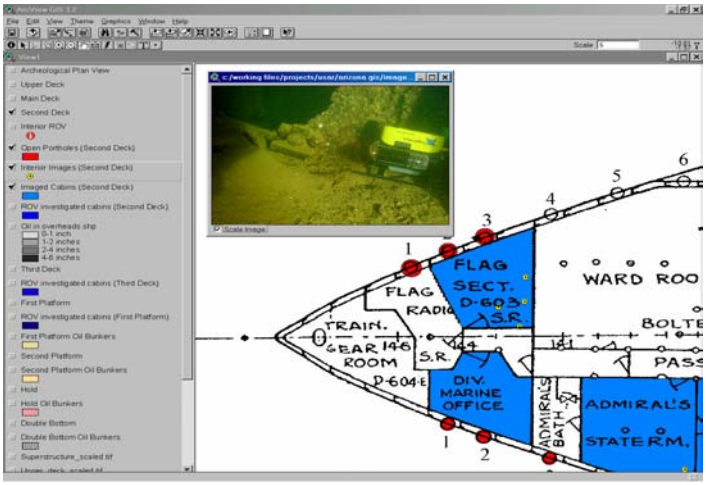
Sub-bottom profiler data collection

During the next field season, five sedimentary core samples will be taken around the hull, three on the port side, and two on the starboard. Vibracoring will be the preferred sampling method. 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 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. These cores will provide stratigraphic correlation for precise sub-bottom profile record interpretation.

VIII. Geographic Information System (GIS) Development

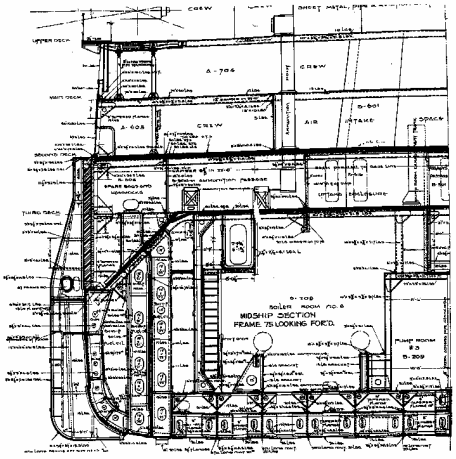
Geographical information systems allow researchers to incorporate different types of data such as maps, plans, graphs, video and photographs into a single, cumulative, spatially referenced database for rapid display and manipulation. Primary electronic data is being consolidated into a single GIS database, including existing plans and technical drawings, photographs and results from archeological fieldwork. This GIS, which will comprise the full data set, will be made available to the public and other researchers through the Internet.



Arizona Geographical Information System (GIS)

Scanned Historical Plans

The NPS and University of Nebraska have located 25 rolls of microfilm with original ship's plans for *Arizona* and *Utah*, totaling nearly 9,000 individual frames. NPS-SRC contracted with Inter-Analog to scan this archival microfilm.



Frame 75 cross section

Images were scanned as greyscale, uncompressed TIF images at 200 dpi, full size. Images were cropped and deskewed, and an unsharp mask filter was applied during the scanning process. TIF images were converted to a Mr. SiD format. Mr. SiD images were provided on archival-quality CD, while the uncompressed TIF images were provided on 75 archival-quality DVDs. These plans are being sorted and added to the GIS project for easy accessibility. In addition, they will form the foundation for building an accurate FEM.

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 multi-disciplinary 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. 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 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 during FY2003 and FY2004.