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UNCLASSIFIED NAVSEC-6136-77-9 NL

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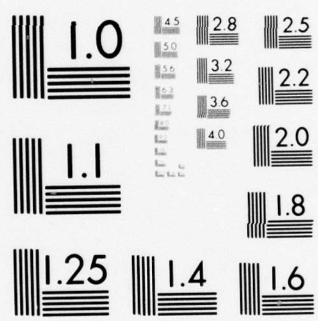

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SHIP UNDERWATER MAINTENANCE, EVALUATION, & REPAIR (SUMER) MASTER PLAN

DEPARTMENT OF THE NAVY
NAVAL SHIP ENGINEERING CENTER

NAVSEC REPORT 6136-77-9

FEBRUARY 1977

PREPARED FOR
NAVAL SEA SYSTEMS COMMAND

(15)

Contract No. N00024-76-C-4543

Prepared by: Advanced Marine Enterprises, Inc., Arlington, VA 22202

New

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SHIP UNDERWATER MAINTENANCE, EVALUATION, & REPAIR (SUMER) MASTER PLAN

and

DEPARTMENT OF THE NAVY

NAVAL SHIP ENGINEERING CENTER

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(11) FEBRUARY 1977

(12) 626 p.

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PREPARED BY:

advanced marine enterprises, incorporated

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ABSTRACT

SHIP UNDERWATER MAINTENANCE, EVALUATION AND REPAIR

(SUMER)

MASTER PLAN

This study proposes a plan of action to implement the actions necessary for a total program of ship hull husbandry and waterborne maintenance and repair. Serving as a focal point for technology transfer, the Master Plan is designed to coordinate a smooth transition between research and development and ultimate fleet implementation. Ongoing efforts and existing hardware and techniques are identified, as well as gaps yet to be filled.

Five principal areas ~~are~~ addressed ~~.~~ are :

(1) SHIP UNDERWATER COATINGS;

(2) NON-COATING PROTECTION SYSTEMS;

(3) FOULING DIAGNOSTICS AND INSPECTION METHODS;

(4) WATERBORNE CLEANING; and

(5) WATERBORNE REPAIR MEASURES.

SHIP UNDERWATER MAINTENANCE, EVALUATION & REPAIR
(SUMER)
MASTER PLAN

CONTENTS

SHIP UNDERWATER MAINTENANCE, EVALUATION & REPAIR

(SUMER) MASTER PLAN

INTRODUCTION

The SUMER Master Plan provides for the direction, management and implementation of a comprehensive U.S. Navy ship hull underwater husbandry and waterborne maintenance and repair program.

The objectives of this plan are to help achieve a more efficient usage of energy in the marine environment, to provide the capability for increased ship performance and availability, and to adjust to increases in the intervals between ship drydocking. The Navy fuel savings resulting from reduced fouling of ship underwater bodies has been estimated to be as much as 120 million dollars annually. This plan outlines a means of accomplishing this result for an expenditure of only a fraction of that amount.

Cleaner hulls mean less power expended to maintain a given speed; hence reduced fuel requirements. Tentative fuel savings of up to 15% have been indicated as a result of recent Navy ship hull cleanings.

Total ship performance is improved by waterborne cleaning and maintenance. A clean dome greatly enhances sonar efficiency. Periodic cleaning maintains the effectiveness of the Prairie Masker System. Removal of fouling significantly reduces ship self-noise, further increasing Anti-Submarine Warfare (ASW) effectiveness. When maintenance and repairs can be done with the ship waterborne (as opposed to drydocked), turn-around time is greatly reduced.

With technologies which are currently available or under development, a potentially high probability exists for supporting the extension of drydocking intervals from 3 years to as long as 5 to 7 years.

The Program Master Plan consists of the following five separately developed appendices, each on a different subject, and an overall program summary:

<u>Subject</u>

Project Summary

Appendix A - Ship Underwater Coatings

Appendix B - Non-Coating Protective Systems

Appendix C - Fouling Diagnostics and Inspection Methods

Appendix D - Waterborne Cleaning

Appendix E - Waterborne Repair Measures

Each appendix gives a detailed description of the current state-of-the-art and further developmental requirements, as well as recommendations for implementation. Each contains references to commercial and industrial manufacturers/distributors of the available systems and devices functionally described. Footnotes and comprehensive bibliographies are included.

SUMER recommendations are presented in the Summary section in two categories: <u>Management Recommendations</u> (gold pages) and <u>Program Recommendations</u> (blue pages). The Management Recommendations cover areas of effort which do not require additional or significant allocation of resources, such as: "maintain continued liaison with cognizant Environmental Protection Agency officials", etc. Program Recommendations, on the other hand, involve funding commitments, research facilities usage, establishment of managing authorities, etc.

Also included in the summary are a series of tables (pink pages) which expand on the requirements of each Program Recommendation. For each item listed, the following amplifying information is given: The appropriate Appendix Page Reference for more detailed background information, the Action required to accomplish this task, relative Priority (A = Most Important, B = Important, C = Less Important), estimated amounts of Funding needed and the Type (O&MN, RDT&E, OPN, etc.), and estimated Time to complete this task.

It is to be noted that each Appendix, though developed and presented as a separate study, must be considered in the total context of all five elements (appendices) of the program. Inherent in this approach is a certain degree of overlap as well as complementarity. An integrated systems approach to the total program is essential to ensure a smooth transition between:

- Research
- Fleet Requirements
- Facilities Allocation
- Procurement
- Implementation
- Information Feedback

Such an approach would eliminate duplication of effort, take advantage of synergistic developments, avoid or resolve technological conflicts, and coordinate efforts for a balanced program.

The Program Master Plan presented herein provides for unified, technologically coordinated direction of all Navy programs involving ship underwater hull maintenance, evaluation, and repair, as well as the monitoring of and liaison with non-Navy programs. By means of this program, the Navy will be able to conserve resources by minimizing duplicative or unproductive effort and by taking full advantage of new cost-effective developments that arise either within or outside the Navy.

A single, centrally controlled program is required to ensure that a systems approach is taken to manage all Navy underwater body maintenance efforts in a cost-effective manner. The program is perceived as largely a management function, but a strong technical staff will be required to analyze, evaluate, and make credible recommendations and decisions concerning the projects and systems that the total program will encompass. The SUMER program consists of a wide variety of subjects, a large number of diverse participants, and is worldwide in scope. The program will require utilization of a highly responsive management information system to effect overall coordination and control. A computer-assisted management information system will provide a comprehensive and responsive management tool for timely and cost-effective support of the program. Such a system is essential as a means of providing quantitative visible evidence of accomplishment of objectives for presentation to higher authority. This system should be designed with the following capabilities:

- Task management (scheduling, automated deadlines, reminders, progress and cost tracking/feedback)
- Individual cost accounting for each task

- Information dissemination (automated mailings to cognizant personnel/activities)
- Identification of interdependences, elimination of duplication, and resolution of conflicts
- Periodic computer-generated reports, tables, and graphical portrayal of trends, savings versus expenditures, etc.
- Technical information storage and retrieval via master data bank

Since the management information system and associated data banks must be fully operational and current well before any program implementation, it is necessary to initiate establishment of them as soon as possible. Immediate commencement of this computerized system will provide the transitional support necessary for a smooth start of the overall project. This type of preliminary coordination is necessary for a logical and orderly reallocation of resources for an efficient transition to the principal program efforts.

It is anticipated that FY79 will be the first year in which significant funding will be available to implement the major elements of the SUMER program. Therefore, it is expected that several overlapping phases will be involved in the complete development and implementation of the master plan. Elements to be included in the various phases must be selected from specific recommendations submitted herein. A determination of the elements to be incorporated, including sub-components, must be made and priorities established. The guidelines and policy to be observed must be established by the program manager with the assistance of the staff and other Navy activities involved. It is envisaged that total development and implementation of the master plan will consist of the three phases discussed below. Phases I and II should occur prior to commencement of FY79, at which time it is anticipated that the first major support funding block will be identified.

Phase I

Policy/Organizational Phase. This phase considers those elements immediately applicable to program initiation and include:

- Development of overall policy, objectives and guidelines
- Establishment of a computer-assisted management information system
- Evaluation of recommendations
- Verification/establishment of priorities
- Establishment of coordinating authorities
- Determination and selection of desired end products
- Establishment of a program for technology transfer
- Examination of ship design elements for greater facility in waterborne tasks
- Establishment of a program to identify from maintenance and repair activities and the Fleet those tasks not already being done due to deficiencies in capabilities.

Phase II

Task Development Phase. This phase involves follow-up procedures including:

- Development of inspection/reporting procedures and formats to fulfill Phase I requirements

- Personnel assignment and policies
  - Feasibility studies, e.g., divers vs. surveyors
  - Investigation of the transitioning of all Navy cleaning tasks to Navy Divers
  - Development of training programs
- Refinement of recommended research programs
  - Determination of task assignments (Lab, Contractor, etc.)
  - Determination of levels of efforts
- Milestone considerations
- Determination of diagnostic techniques
- Selection of fleet support pilot units
- Development of Test and Evaluation procedures

Phase III

Task Activation Phase. This phase initiates program activation (assumed to be commencement of FY79) and includes:

- Activation of immediately feasible task efforts: commence RDT&E efforts, etc.
- Acquisition of required Navy approved equipments
- Procurement of commercial items/systems for evaluation/operation
- Continue to maintain computer-assisted management information system and data banks
- Development of test, inspection, monitoring procedures
- Establishment of program validation methodology

MANAGEMENT RECOMMENDATIONS

Ship Underwater Coatings (Appendix A)

- Continue to use the Navy's current cuprous oxide (Formula 150/Formula 121/63) hull coating system until a system is developed which offers a major improvement (e.g., doubles the service life) over the present system.

- The additional cost associated with the application and removal of tin-based antifouling paints should be carefully weighed against the benefits derived from employing this type of coating on Navy ships.

- Establish liaison between the RDT&E community which is striving to develop new and better marine coating systems and the Shop 71 painters who are tasked with applying these systems at the Naval shipyards. Liaison can be accomplished via the existing NAVSEA Steering Group.

- As a minimum, monitor the results of the marine coating panel tests being conducted by the Coast Guard/Battelle Laboratories at Daytona Beach, Florida. Consider joint funding sponsorship of this valuable on-going work.

- Closely monitor the Navy's Manufacturing Technology Projects. Make recommendations concerning projects which should be undertaken to improve paint application and/or removal methods and to facilitate drydock cleanup.

- The Navy should maintain liaison with the Environmental Protection Agency (EPA) Office of Pesticides to acquire extensive data on marine pesticides.

- Continue to keep informed of EPA hydrocarbon control studies for potential regulations pertaining to spray painting operations.

- Continue to keep abreast of the work being done at Battelle Columbus Laboratories regarding solvent-free coatings and their application methods. This is a most valuable alternative for solution of the hydrocarbon emission problem during hull painting operations.

- Establish contact with the JOTUN Marine Coating Company and the commercial shipping lines using the Seamaster System to monitor the results of the service tests now in progress.

- Continue study and implementation of measures for drydock clean-up. Maintain liaison with the Department of Commerce to obtain information on the study being conducted at Avondale Shipyards.

- Determine the actions necessary for compliance with the Toxic Substances Control Act, which was enacted on 12 October 1976, and Federal Standard 313A, which was promulgated on 4 June 1976.

- Study the results of the drydock water effluent monitoring work which has been in progress for several years. Prepare to make constructive meaningful comment upon drydock effluent standards proposed by EPA.

MANAGEMENT RECOMMENDATIONS

Non-Coating Protective Systems (Appendix B)

- Impressed current cathodic protection systems should continue to be installed on surface ships. It is recommended that these protection systems be installed during the initial construction of ships rather than as a retrofit in the form of SHIPALT.

- SHIPALT's for installation of impressed current systems in amphibious ships should be changed from "D" to "K", which would permit central funding. This would allow a higher priority to the SHIPALT accomplishment at each ship's next scheduled regular shipyard overhaul (ROH).

- An awareness should be maintained of the progress of emerging technologies which represent advancements in the state-of-the-art of fouling protection, such as the electrolyzed seawater systems.

- Navy programs should be continued in the area of stray current corrosion evaluation with emphasis on the location of sources.

MANAGEMENT RECOMMENDATIONS

Fouling Diagnostics and Inspection Methods (Appendix C)

Underwater Inspection Recommendations.

It is recommended that an integrated underwater hull inspection program be developed, details thereof contained in section entitled "Program Recommendations," which incorporates the following:

- Emphasis on evaluation, and further development where necessary, of available commercial underwater inspection related equipments before pursuing independent research and development of new systems.

- An equipment evaluation approach should be developed based on the following:

  - An organized evaluation team consisting of Navy laboratory, shipyard Non-Destructive Testing (NDT), Navy Photo Center, and shipyard/tender diving and engineering personnel.

  - Selection of the most promising equipment and evaluation in terms of training requirements, operability, reliability, maintainability, support, and human engineering factors.

  - Collection and processing of required data to obtain service approval for equipment procurement.

  - Issuing approved equipment to fleet units and providing appropriate training.

- Expedite the development, test, and evaluation of tools, equipment, techniques, and procedures.

- Funding of inspection-related tools and equipment should be controlled at NAVSEA and that initial allowances and new approved equipment should be centrally funded instead of funding by user activities.

Fouling Diagnostic Recommendations

- Until a formal fouling diagnostic program provides a better alternative, ships should comply with procedures recommended by current Navy programs. Navy ships in tropical waters should be cleaned at 4-6 month intervals; ships in temperate waters should be cleaned at 9-12 month intervals. Underwater inspections should occur every 3 months.

- Establish a fouling diagnostics data bank. All data on fouling trials and feedback from underwater diagnostic inspections should be included in this data bank.

MANAGEMENT RECOMMENDATIONS

Fouling Diagnostics and Inspection Methods (Appendix C) cont'd.

- Torsionmeters should not be procured and installed on ships solely for use as fouling diagnostic tools unless programs show conclusively that no other less costly method will be available in the near future.

- Ships equipped with torsionmeters should be required to traverse existing measured ranges (e.g., Guantanamo Bay, Cuba; Roosevelt Roads, P.R.; Barbers Point, Oahu, etc.) when in the vicinity of such ranges. Shaft Horsepower (SHP) and other appropriate data should be recorded for later evaluation and analysis.

- Ship performance out of drydock should be cataloged to form a baseline for diagnostics. Performance parameters should be tailored to individual ships. For example, High Pressure turbine pressure, torsionmeters, speed logs, etc., may be most appropriate for some ships, while others may employ fixed ranges and precision navigation (OMEGA, SATNAV) in place of speed logs.

MANAGEMENT RECOMMENDATIONS

Waterborne Cleaning (Appendix D)

- Establish a policy, and the necessary appropriation support, to clean ship hulls when a certain speed/power threshold has been exceeded.
- An investigation should be made for transition to sole use of Navy divers for appropriate cleaning efforts.

MANAGEMENT RECOMMENDATIONS

Waterborne Repair Measures (Appendix E)

- Review compensation policies and personnel procurement, training and employment practices to establish the basis for developing a cadre of qualified craftsmen and technicians in selected naval shipyards and tenders to carry on a sustained program of waterborne underwater hull maintenance, repair, and inspection for Navy ships. Develop a plan for initiating these revised employment practices in the Navy.

- Establish a program to get feedback from maintenance and repair activities to identify those waterborne repair tasks which are possible but are not now being done.

- Examine ship designs for possible incorporation of features which will aid in waterborne repair and maintenance.

PROGRAM RECOMMENDATIONS

Ship Underwater Coatings (Appendix A)

- Consider the adoption of the "Pit Stop" Method of drydocking as a means of averting increased fuel consumption due to hull fouling. The method provides for an interim docking of a ship if necessary.

- Determine the feasibility and cost effectiveness of constructing additional drydocks to alleviate the perpetual backlog of ship overhauls. Study the possibility of deepening existing drydocks which have been obsoleted due to a lack of deep draft docking capability.

- Continue exploratory development of organometallic polymer coatings.

- Investigate the desirability of developing a method for detoxification of organotin debris which will allow for its safe and economic disposal.

- Ascertain whether the disposal requirements applicable to wastes containing organotin paints should be applied to wastes generated during the application and removal of tributyltin oxide-based coatings.

- Complete the work already in progress of re-formulating the cuprous oxide based antifouling paints, Navy Formulas 121/63 and 129/63, so as to obtain compliance with hydrocarbon emission limitations.

- Establish standards for the maximum acceptable degrees of marine fouling on various ship types based on a comparison of the costs associated with waterborne brushing/coating replacement versus the cost of increased fuel consumption at different levels of hull fouling.

- Update and re-publish the chapter of the NAVSHIPS Technical Manual covering preservation of ships in service.

- Resume performance appraisal or evaluation of underwater coatings on active Fleet ships in the "as docked" condition.

- Continue to monitor the performance of B.F. Goodrich "NO-FOUL" on Navy ships. Ascertain the effectiveness and repairability of the product on hull appendages (e.g., rudders, struts, roll stabilization fins, etc.) which are subjected to high velocity water flow, and also in sea chests.

PROGRAM RECOMMENDATIONS

Non-Coating Protective Systems (Appendix B)

- Allocate funding and initiate a program to study the problem of underwater electric potential fields associated with impressed current cathodic protection systems on submarines. A parallel effort should be undertaken to develop a controller and power supply for Surface Effect Ship (SES) use. The controller should have provisions for current suppression and should be fail-safe. The power supply should be of the saturable reactor type with maximum current limiting circuitry and current bypass circuitry to allow reduction of output to zero amperes.

  A program is also needed to develop and evaluate a SUBSAFE submarine hull penetration fitting for anode attachment in the pressurized hull area, and a non-pressure hull type alternate fitting.

- Initiate research programs and allocate funding to support the Surface Effect Ships (SES) application of impressed current cathodic protection systems in the following areas:
  - Remote Anode Studies
  - Effect of Protection Potentials on Titanium and 17-4PH Stainless
  - Hull Anode Design
  - Controller and Power Supply Design
  - Velocity Effects on Dielectric Shield Materials at High Velocity (50 to 100 Knots)
  - Pilot System Installation Evaluation

- Continue to evaluate foreign technology in the areas of anticorrosion and antifouling systems. Antifouling systems which merit further immediate attention include the operational Japanese electrolyzed seawater system, the British TOXION TWO system, the Belgian CEPI/COMAV device, and the American AQUATRON system.

- Develop prototype full ship hull chlorine antifouling systems and conduct sea trials of the prototype system.

- Immediately fund additional development efforts to support current and future needs of galvanic anode technology, such as the development of specifications for aluminum anode composition and the development of environmentally acceptable anode materials.

- Initiate and fund development programs to adapt existing shelf hardware to provide full hull fouling prevention to submarines and surface ships. Two such candidate systems are the electrolytic hypochlorinator and the electrolyzed seawater systems.

- Fund evaluation of feedback type control system hardware for seawater system chlorination.

- Modify the Impressed Current Cathodic Protection system training material and training courses to cover a broader group of ships personnel and arrange to provide training on both the east and west coasts of the United States.

PROGRAM RECOMMENDATIONS

Fouling Diagnostics and Inspection Methods (Appendix C)

- Direct R&D effort to develop high accuracy speed logs. The initial effort should be directed to modification of existing types to improve accuracy or repeatability.

- Investigate the correlation of propulsion plant parameters such as condensate flow, steam quality, etc., with shaft horsepower and ship speed. The effort may either improve or complement the level of information derived from the correlation of the high pressure turbine shell pressure with shaft horsepower.

Underwater Inspection Recommendations

Specific recommendations related to the development of an underwater hull integrity or seaworthiness inspection program are categorized as follows:

- Diver Life-Support Equipment

  - Provide approved life-support equipment to each hull husbandry diving activity to ensure that each activity has a complete inventory of approved equipment for shallow water diving.

  - Develop a new diver face mask which does not restrict visibility for hull husbandry divers.

  - Approve the UNI-SUIT or comparable type suit for use in a variable volume configuration and procure same for hull husbandry use.

  - Procure currently approved diver air compressors for each hull husbandry diving activity.

  - Approve a surface-supplied divers' umbilical for hull husbandry use and provide same to each hull husbandry diving unit.

- Video Equipment

  - Evaluate commercially available underwater T.V. systems, including color, to determine if they have greater capability than UDATS for underwater hull inspections. This evaluation should include the feasibility of utilizing components of the system such as lights and cameras with existing UDATS monitoring and controlling equipment and standardization of component cable interfaces of TV systems so that improved components can be added as they are developed.

PROGRAM RECOMMENDATIONS

Fouling Diagnostics and Inspection Methods (Appendix C) cont'd.

- Measurement Instruments

  Develop measuring instruments for the following functions:

  - Tank liquid level, including oil/water interface
  - Fouling level, quantification of
  - Surface profile/roughness for both hull and propeller
  - Leak detection
  - Corrosion rate (local and general)
  - Coating effectiveness
  - Crack detection (may be by NDT device)
  - Hull plate thickness (may be by NDT device)
  - Radiation detection

- Non-Destructive Test (NDT) Equipment

  Evaluate commercially available wet magnetic particle, ultrasonic, eddy current, and gamma radiography test equipment for Navy use.

- Boats

  Designate a boat such as the LCM-3 configured in NAVSEA Drawing No. 145-4777404 as the standard diver work boat for afloat activities. Procure and completely outfit same for each afloat hull husbandry diving activity. For more efficient operation, ashore activities may require a larger boat.

- Swimmer Locator/Navigation System

  Immediately initiate a high priority underwater hull coordinate location R&D effort to include the development of:

  - A swimmer area navigation system
  - A lightweight net grid and/or a two-line triangulation location device

PROGRAM RECOMMENDATIONS

Fouling Diagnostics and Inspection Methods (Appendix C) cont'd.

- Software

  - Immediately develop a training program for Navy divers on hull fouling inspection/diagnostic procedures. Coverage to include foulant identification and their growth characteristics and effects on the ship's power as a function of location, size, and density as well as the relative importance of fouling properties.

  - Immediately institute a training program on qualifying hull inspectors/surveyors at shipyards and other maintenance activities as shallow water divers.

  - Provide standards for evaluating underwater inspection results to the underwater inspector. For hull integrity inspections, these standards should be as close as possible to existing drydock inspection standards. For fouling diagnostics, divers should be provided with color photographs of hulls in various conditions of fouling with an approved verbal description of the fouling level.

  - Standardize underwater hull inspection procedures and reports.

  - Reissue the Underwater Work Techniques Manual to all hull husbandry diving activities. Update the manual to include inspection standards.

  - Update the Sonar Dome Handbooks, Volumes I through IV (as has been done with Volume V) to include underwater hull inspection requirements and procedures, with particular applicability to AN/SQS-26 sonar domes.

- Fixed, Remote, and Mobile Inspections Systems

  - Designate one port on each coast with clear water and little current as a hull integrity inspection facility.

  - Undertake feasibility studies to determine the cost-effectiveness of fixed and mobile inspection facilities.

  - Develop a mobile inspection vehicle for ship inspections and evaluate same for use as an inspection vehicle. Include underwater lighting, TV, and a manipulator arm fitted, for example, with devices for sea chest inspection and cleaning in the design.

  - Evaluate inspection systems such as SCAN for Navy use.

PROGRAM RECOMMENDATIONS

Waterborne Cleaning (Appendix D)

- Accomplish cleaning by established commercial firms in the principal operating areas under a master contract or contracts. The reason for this is ethical constraints on licensors of commercial cleaning systems against establishing competing facilities to their licensees in the same geographical area.

- Initiate R&D or follow commercial development work to reduce the minimum radius of curvature accommodated by multiple brush systems. This is to reduce the percentage of a combatant ship hull which must be cleaned with diver-held rotary brushes.

- Establish a research program to determine whether high pressure water jet systems or cavitation erosion systems similar to CAVIJET offer superior cleaning capabilities to brush systems in

    - Protection of antifouling coating

    - Recurrence of fouling

    - Flexibility in tight areas

- Should water jet systems show potential superiority to brush systems, an RDT&E program should be initiated to develop prototype units of ganged water jets which will match the productivity of brush systems.

- Continue the study of the biology of fouling organisms, not only to provide the basis for improved antifouling toxins, but also for improvement in waterborne cleaning methods.

- As new antifouling formulas are developed, parallel research programs should be established to develop new brush or waterjet techniques most compatible with the new coatings.

PROGRAM RECOMMENDATIONS

Waterborne Repair Measures (Appendix E)

- Develop ship design standards to facilitate waterborne maintenance and repair operations. Hex or Allen head screws should be used exclusively, vice slot headed screws. Welding should be eliminated as a means of attaching removable items, except where vibration could affect the fasteners. Tackwelding should be considered for this. Sea chest gratings should be hinged to provide access. Zincs should be bolted on. A hydraulic "Pilgrim Nut" should be used to fasten the propeller to the shaft.

- Develop guides to underwater Non-Destructive Testing (NDT) and inspection. Concurrently with this task, begin an evaluation program to determine which inspection equipment is most effective for Navy use. Such evaluation would aid in obtaining approval for equipment procurement.

- Study overall tool and support equipment requirements and equip key naval shipyards and tenders with a complete stock of NCSL-developed hydraulic tools and power supplies, hydraulic propeller puller, underwater cleaning and welding equipment, shallow water diving equipment, inspection and other support equipment necessary to effect the full range of feasible underwater repairs.

- Review the requirements for and feasibility of designing and building a family of standard partial docks (such as side-fitting cofferdams to match currently planned bow docks), and both one-atmosphere and ambient pressure habitats and cofferdams for the performance of underwater work in the dry. Determine the feasibility of flexible seals for different hull curvatures.

- Investigate the feasibility of improving visibility for inspection and repair tasks by the development of localized pockets of clear water, or the provision of complete wet docks containing filtered ambient water.

- Continue the development of coatings and adhesives and wet application techniques to improve their quality and ease of application.

- Contract with an appropriate laboratory and/or diving company to complete any necessary additional development work to demonstrate shipyard quality welds in a dry ambient pressure habitat.

- An R&D Program should be initiated to upgrade hull welding by the localized cofferdam procedure and to establish process specifications for the procedure. Objective would be the achievement of shipyard quality welds in high-strength steels or a quality level comparable with this level.

- For wet-welding procedures and specifications, special attention should be directed to hydrogen effects. In view of the Navy's prior experience with the technique, this R&D Program should be pursued within the Navy.

PROGRAM RECOMMENDATIONS

Waterborne Repair Measures (Appendix E) cont'd.

- Investigate equipments and techniques necessary to implement waterborne "patch-painting" (touch-up painting in cofferdams and in the wet).

SUMER PROGRAM PLAN

TITLE Ship Underwater Coatings

APPENDIX A

ITEM	APP REF PAGE	ACTION REQUIRED	*	ESTIMATED FUNDING & TYPE	ESTIMATED TIME TO COMPLETE
1. "Pit Stop" method of drydocking/coating replacement	A62 A68	Establish a master contract with selected commercial shipyards and implement the "Pit Stop" program. NOTE: $7.4M for first five yrs. for doing all ships once btwn major overhauls. Funded by Type Cmdr.	A	$7.4M avg. per annum for first 5 ys. O&MN	continuous
2. Construction of additional drydocks/	A65	Conduct a study to determine the cost effectiveness of: . constructing additional deep draft drydocks . deepening existing drydocks at selected Naval Shipyards.	A	$300K MCON	1 year
3. Organometallic Polymer Coatings	A77	Continue to fund RDT&E efforts to develop OMP antifouling paints.	A	$1.7M RDT&E	5 years
4. Detoxification of Organotin Debris	A10	Continue to fund RDT&E project currently underway.	A	$150K RDT&E	1 year
5. Goodrich "NO-FOUL" Waste Products	A103	Ascertain if disposal requirements applicable to wastes containing organotin paints should be applied to wastes generated by application and removal of "NO-FOUL"	A	$100K RDT&E	1 year
6. Reformulation of Navy Formulas 121/63 and 129/63.	A75	Complete the work in progress of revising formulations and MILSPECS for these antifouling coatings to comply with hydrocarbon emission limitations. NOTE: The reformulation has been completed. Revised specs currently under review/Est'd date of publication: Dec 77.	A	None reqd.	1 year

*PRIORITY: A = MOST IMPORTANT B = IMPORTANT C = LESS IMPORTANT

SUMER PROGRAM PLAN

TITLE Ship Underwater Coatings

APPENDIX A

ITEM	APP REF PAGE	ACTION REQUIRED	*	ESTIMATED FUNDING & TYPE	ESTIMATED TIME TO COMPLETE
7. Establish maximum acceptable degree of fouling standards for use fleetwide	A73	Initiate RDT&E project to determine such standards	A	$650K RDT&E	3 years
8. NAVSHIPS Technical Manual, Chapter on Preservation of Ships in Service	A76	Update this chapter to reflect current ship preservation practices. NOTE: In process - est'd completed date: 30 Sept 77.	B	None reqd.	6 months
9. Performance Appraisal of Underwater Hull Coatings	A75 A88	Resume performance appraisal or evaluation of underwater coatings in "as docked" condition and incorporate info in data bank.	B	$50K per annum O&MN	continuous
10. Goodrich "NO-FOUL"	A103	Continue to monitor the effectiveness of "NO-FOUL" on hull appendages and sea chests.	B	$400K RDT&E	5 years

*PRIORITY: A = MOST IMPORTANT B = IMPORTANT C = LESS IMPORTANT

SUMER PROGRAM PLAN

TITLE Non-Coating Protective Systems

APPENDIX B

ITEM	APP REF PAGE	ACTION REQUIRED	*	ESTIMATED FUNDING & TYPE	ESTIMATED TIME TO COMPLETE
1. Develop ship hull chlorine antifouling system	B-45 B-40	• Design prototype system concept for ship application • Perform prototype evaluation tests • Evaluate environmental impact	B	$600K RDT&E	3 years
2. Conduct sea trials of ship hull antifouling system (Chlorine Dispersal System)	B-45 B-40	• Manufacture and install U.S. Navy surface ship and submarine EDM Models of systems • Perform Navy TechEval and OpEval certification tests	B	$100K O&MN, & $300K RDT&E	2 years
3. Continue evaluation of U.S. materials (Cu-Ni) development and Japanese electrolyzed seawater system	B-45 B-40	• Continue evaluation of materials development and system concepts to determine applicability to Navy needs	B	$80K $80K RDT&E	2 years
4. Conduct evaluation of U.S., Japanese and Russian hull antifouling systems	B-46 B-42	• Conduct in-depth comparative evaluation of coating, chlorine dispersal, and ultrasonic systems effectiveness	B	$100K RDT&E	18 months
5. Evaluate chlorine effect on internal seawater system surfaces	B-46 B-45	• Determine effect of electrolytically generated chlorine on ship systems thru experimental ship systems tests	A	$100K RDT&E	2 years
6. Determine adequate chlorine dosage rate	B-46 B-45	• Experimental determination of hypochlorite quantities and effective operating cycles for fouling control	A	$150K RDT&E	2 years
7. Evaluate seawater chlorine system feedback instrumentation	B-46 B-45	• Conduct survey of commercially available instruments, or • Develop instrument to provide monitoring and automatic feedback control functions.	A	$60K RDT&E	2 years

*PRIORITY: A = MOST IMPORTANT B = IMPORTANT C = LESS IMPORTANT

SUMER PROGRAM PLAN

TITLE Non-Coating Protective Systems

APPENDIX B

ITEM	APP REF PAGE	ACTION REQUIRED	*	ESTIMATED FUNDING & TYPE	ESTIMATED TIME TO COMPLETE
15. Conduct sea trials of submarine antifouling system	B-47 B-43	• Perform Navy OpEval, TechEval certification tests of full hull submarine antifouling system	B	$400K RDT&E	2 years
16. Continue design development of ICCP anode placement in seawater systems	B-43	• Conduct evaluation of anticorrosion effects of impressed current flows in systems • Develop system design concepts • Perform Navy certification tests	B	$200K RDT&E	3 years
17. Perform remote anode studies to allow elimination of dielectric shields on Surface Effect Ships (SES)	B-36	• Conduct a feasibility study and develop a working design for a remote anode	C	$50K RDT&E	18 months
18. Determine effects of protection potentials on SES titanium and 17-4 PH stainless steel	B-36	• Conduct experiments to determine if the highly electronegative potentials associated with ICCP systems cause hydrogen embrittlement on titanium and 17-4 PH stainless	C	$50K RDT&E	18 months
19. Determine velocity effects on dielectric shield materials for SES application of ICCP systems	B-36	• Perform high velocity effect tests on candidate dielectric shield materials at 50-100 knots	C	$60K RDT&E	2 years
20. Evaluate the performance and design of impressed current cathodic protection system on SES craft	B-36	• Install a pilot ICCP system onboard a 100-ton SES to verify the design and current data prior to installation on a 2000-ton SES	C	$50K RDT&E	1 year

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SUMER PROGRAM PLAN

TITLE Fouling Diagnostics and Inspection Methods: Fouling Diagnostics

APPENDIX C

ITEM	APP REF PAGE	ACTION REQUIRED	*	ESTIMATED FUNDING & TYPE	ESTIMATED TIME TO COMPLETE
1. Establish and maintain Data Bank on Fouling Diagnostics	C-17 C-20	Establish and maintain a comprehensive data bank on all aspects of hull fouling diagnostics needed to arrive at cost-effective diagnostic parameters and cleaning decisions.	A	$850K over 1st 5 yrs. RDT&E	3 - 5 yrs. Continuing
2. Expand baseline data accumulation work including propulsion plant parameters and speed log Development/Evaluation	C-18 C-19 C-20	Additional fouling diagnostic techniques/systems should be pursued in order that the most cost-effective system can be developed	B	$1.75M over 5 years RDT&E	3 - 5 yrs.

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SUMER PROGRAM PLAN

TITLE Fouling Diagnostics and Inspection Methods: Inspection Methods

APPENDIX C

ITEM	APP REF PAGE	ACTION REQUIRED	*	ESTIMATED FUNDING & TYPE	ESTIMATED TIME TO COMPLETE
1. Develop underwater hull inspection program	C-23 C-24 C-25	Develop total inspection system which integrates inspection procedures, personnel, training, tools, and reports for both fouling diagnostic purposes and hull integrity or seaworthiness purposes NOTE: Shortest time to complete period indicates accelerated program	A	$950K over five yrs. RDT&E	2 - 5 yrs.
2. Develop Measurement instruments	C-21 C-22 C-26	Develop instruments for quantifying fouling and the physical condition of underwater hull and appurtenances to support 5 - 7 year drydocking cycles	A	$425K over 1st 5 yrs. RDT&E	continuing
3. Develop Locator System	C-23 C-26	Develop precise system for locating damage, localized hull deterioration, corrosion products as well as general and localized fouling	B	$200K over 1st 5 yrs. RDT&E	continuing
4. Develop Hull Inspection Platform (HIP) System	C-25 C-26	Redesign and evaluate HIP system which does not rely totally on divers as "inspectors"	B	$300K RDT&E	1 - 2 yrs.
5. Evaluate a system such as SCAN	C-25 C-26	Evaluate a system such as SCAN, which may provide an effective underwater inspection device for use in some U.S. Navy ports	B	$100K over 2 yrs. RDT&E	1 - 2 yrs.
6. Evaluate Underwater NDT Equipment	C-22 C-26	Evaluate and modify as required commercially available NDT equipment for Navy use NOTE: See also recommendation of Appendix E	B	$350K over 5 yrs. RDT&E	continuing

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SUMER PROGRAM PLAN

TITLE Fouling Diagnostics and Inspection Methods: Inspection Methods

APPENDIX C

ITEM	APP REF PAGE	ACTION REQUIRED	*	ESTIMATED FUNDING & TYPE	ESTIMATED TIME TO COMPLETE
7. Develop Clear-Field Viewing Devices	C-16 C-26	Develop/evaluate devices to improve/extend underwater visibility for divers, TV, and photography to support an effective underwater hull inspection program.	B	$125K over 5 yrs. RDT&E	continuing
8. Improve Underwater TV	C-21 C-26	Better resolution/clarity of underwater image is needed for accurate assessment of condition of underwater hull and appurtenances.	B	$475K over 5 yrs. RDT&E	continuing
9. Improve Life-Support Equipment	C-20 C-21 C-26	Develop/procure more comfortable and efficient diver life-support equipment to optimize diver contribution to underwater hull inspection and maintenance	C	$250K over 5 yrs. RDT&E	continuing

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TITLE Fouling Diagnostics and Inspection Methods: Inspection Methods

SUMER PROGRAM PLAN

APPENDIX C

ITEM	APP REF PAGE	ACTION REQUIRED	*	ESTIMATED FUNDING & TYPE	ESTIMATED TIME TO COMPLETE
10. Conduct Diver-Inspection training	C-58 C-74	Develop and conduct extensive training program to qualify Navy divers as underwater hull inspector/surveyors	A	$550K over 1st 5 yrs. O&MN	Continuing
11. Determine feasibility of training inspectors as divers	C-74	Conduct study to determine feasibility of training hull surveyors as divers	A	$50K O&MN	One year
12. Revise and republish Underwater Work Techniques Manual	C-75	Revise, update, and maintain Underwater Work Techniques Manual	B	$135K over 1st 5 yrs. O&MN	Continuing
13. Establish clearwater pilot Fleet Facilities for Inspection/Evaluation	C-81	One or more Navy ports exist which have relatively good underwater visibility conditions. Exploitation of this characteristic should be pursued along with development of clearwater facilities in other ports	C	$400K over 5 yrs. O&MN	2 - 5 years
14. Update Sonar Dome Handbooks	C-77	Update sonar dome Handbooks for surface ships which are currently devoid of meaningful inspection criteria and procedures.	C	$150K over 3 yrs.	1 - 3 yrs.
15. Establish and procure full allowance tools, equipment, and systems for diver-inspection units	C-14 C-17 C-27	Diver-inspection tool and equipment allowances need to be established and procured by central funding to ensure items actually get in the Fleet	A	$2.7M over 3 - 5 yrs. OPN	3 - 5 yrs.
16. Procure Standardized Diver Work Boats	C-22 C-23 C-27	Procure standardized diver work boats, which are essential to standardized procedures and training and effective implementation of an underwater hull maintenance program	B	$1.6M over 5 yrs. OPN/SCN	5 years

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SUMER PROGRAM PLAN

TITLE Underwater Cleaning

APPENDIX D

ITEM	APP REF PAGE	ACTION REQUIRED	*	ESTIMATED FUNDING & TYPE	ESTIMATED TIME TO COMPLETE
1. Funds to clean ships	D-4 D-7 D-11	Budgeting and allocation of funds NOTE: $8 to $32/ft. length of ship depending on extent of cleaning and type of ship. Navy ships currently in the $25/ft av. cost range.	A	O&MN	Annual
2. Master Cleaning contracts	D-4 D-19	Establishment of annual or longer term master ship cleaning contracts NOTE: Costs as indicated in (1) above.	A	O&MN	2-3 mos.
3. Navy operated facilities	D-4	Procurement of a cleaning system, a support boat and diving gear; and training personnel to operate the cleaning system NOTE: Annual operating costs not estimated. See also Appendix C.	B	$614K per team OPN	1.5 - 2 years
4. Improved multi-brush systems	D-4 D-15	Surveillance of commercial developments and evaluation of results NOTE: $50K to $250K per year.	B	RDT&E	Continuing
5. High Pressure water jet	D-4 D-20 D-23 D-25	Continuation of research to develop operating techniques and evaluate effectiveness.	C	$1.5-$2M RDT&E	3-5 yrs.
6. High Pressure water jet	D-4 D-23	Development of ganged water jet systems for increased productivity	C	$1.5-$2M RDT&E	2 - 3 yrs

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SUMER PROGRAM PLAN

TITLE Underwater Cleaning

APPENDIX D

ITEM	APP REF PAGE	ACTION REQUIRED	*	ESTIMATED FUNDING & TYPE	ESTIMATED TIME TO COMPLETE
7. Brush development	D-4 D-15	Continuation of brush development work to optimize for changing coating systems	B	$100K- $150K per yr. RDT&E	Continuing
8. Fouling organisms biology	D-4 D-6	Continuing study	C	$60K- $100K per yr. RDT&E	Continuing

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SUMER PROGRAM PLAN

TITLE Waterborne Repair Measures

APPENDIX E

ITEM	APP REF PAGE	ACTION REQUIRED	*	ESTIMATED FUNDING & TYPE	ESTIMATED TIME TO COMPLETE
1. Ship design Standards	E-5 E-20 to E-35	Development of attachment standards for hull fittings to facilitate waterborne maintenance and repair.	B	$50K- $75K RDT&E	12-18 mos
2. NDT/inspection equipment	E-5 E-51	Evaluation of available equipment for applicability to Navy use, and development of underwater UDT/inspection guides NOTE: See also recommendation of Appendix C	B	$350K RDT&E	5 yrs.
3. Tools and equipment	E-5 E-10 to E-13	Equipment of naval shipyards, tenders and salvage ships with tools for underwater maintenance and repair.	A	$3.1M OPN	2 yrs.
4. Standard partial docks, cofferdams, and work platforsm	E-5 E-13 E-14 E-22 E-26	Initiation of studies of requirements for, and design feasibility of families of partial docks and cofferdams for underwater maintenance and repair.	C	$80K- $120K RDT&E	18 mos.
5. "Clear" wet docks	E-5 E-14	Initiation of a conceptual design and feasibility study	B	$150K RDT&E	1 year
6. Underwater navigation/location system	E-5 E-54	Evaluation of alternative methods for aiding divers in locating their position on the hull, and preparation of procurement specification(s) for selected system(s). NOTE: See also recommendation of Appendix C.	B	$200K RDT&E	2 yrs.

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SUMER PROGRAM PLAN

TITLE Waterborne Repair Measures

APPENDIX E

ITEM	APP REF PAGE	ACTION REQUIRED	*	ESTIMATED FUNDING & TYPE	ESTIMATED TIME TO COMPLETE
7. Coatings and adhesives	E-5 E-24	Continuation of development of wet application techniques for coatings and adhesives.	B	$300K RDT&E	3 yrs.
8. Dry ambient pressure welds	E-5 E-42 to E-48	Continuation of development work to demonstrate shipyard quality welds in all normal hull structural material, and preparation of process specifications.	B	$300K- $500K RDT&E	3 - 4 yrs.
9. Waterborne patch painting	E-24	Implementation of touch-up painting in cofferdams and in the wet. NOTE: $1.5M for each of first five years.	A	$1.5M RDT&E	Continuous

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SYNOPSIS

Dramatic increases in fuel costs coupled with the declining availability of drydocks has spurred new interest in the field of ship underwater body protection and cleaning. Existing protection methods such as anticorrosion and antifouling underwater hull coatings have generally proven inadequate. New coatings or techniques are required to provide greater protection against corrosion penetration, abrasion, and loss of effectiveness to repel marine life.

Biological fouling and deterioration of materials used in marine service necessitate a high annual maintenance expenditure by the Navy, an expenditure of more than 215 million dollars in 1974. This is the direct cost attributable to biological deterioration of wood docks and piers as well as fouling growth on ship hulls.

There is currently a severe shortage of available drydocks in the U. S. for hull cleaning and repair. Only twenty-seven graving docks are available to support the Navy's 484 active ship fleet. In 1976, sixty-nine ships were unable to be accommodated by drydock as originally scheduled. Thus, fourteen percent of the active fleet is currently in need of attention. To alleviate the drydock backlog, new techniques must be developed in ship underwater body protection and cleaning, repair and maintenance. Alternatively, additional drydocks should be built, or new utilization methods employed ("Pit-Stop" method, q.v.), or a combination of both.

This study describes new technology areas of interest and makes recommendations for courses of action to alleviate problem areas.

The five key topics discussed in this report are listed below with a brief description of each.

Appendix A - Ship Underwater Coatings.

This section pertains to the specially formulated surface coverings applied to the ship underwater hull body, apertures, and appendages. These coverings serve to protect the hull and hull structure from oxidation and the attachment of marine life. The discussion includes: the current Navy system, the SEAMASTER system, the self-polishing copolymer system, Goodrich "NO-FOUL," and Navy Formula 1020A.

Appendix B - Non-Coating Protection Systems.

This section covers all corrosion and fouling prevention systems not covered by Appendix A. Specific systems studied include: sacrificial anodes, impressed current cathodic protection systems, fouling control via chlorine distribution in seawater piping systems, the British TOXION TWO seawater antifouling system, the Japanese electrolyzed seawater hull fouling prevention system, and the American AQUATRON scale and algae elimination system.

Appendix C - Fouling Diagnostics and Inspection Methods.

This section details what is involved in the determination of the optimum time and conditions for the cleaning or repairing of ship's hulls. One anticipated outcome of this study is the development of standard procedures for high-confidence of seaworthiness of the underwater hull. The topics covered include: torsionmeters, electrical measurements of hull coating, temperature/flow differential monitoring, propulsion parameter correlation, measured distance at constant RPM, noise measurement, time indexing, and underwater body hull inspections.

Appendix D - Waterborne Cleaning.

This section discusses present and future devices, operations, and constraints pertaining to the waterborne removal of marine fouling from the ship's hull and appendages. Extensive coverage is given to mechanical brushing and water jet cleaning.

Appendix E - Waterborne Repair Measures.

This section covers techniques, equipment, and procedures for routine and emergency repair and maintenance of the ship's hull and appendages while waterborne. The discussion includes the following areas: facility considerations, hull maintenance, appendage maintenance, welding and cutting, and inspection considerations.

SUMMARY

SHIP UNDERWATER COATINGS: (APPENDIX A)

1. INTRODUCTION

This study is concerned with marine coating systems which are applied to the submerged portions of a ship's hull. Normally, a marine coating system is comprised of two major components - an anticorrosive coating to protect the hull from oxidation, and an antifouling coating to prevent the attachment of marine organisms. The need for corrosion protection is critical since an unprotected metallic hull submerged in seawater will eventually deteriorate and fail. Marine fouling on a ship's hull, propeller, and appendages (e.g., rudder, struts, roll stabilization fins, etc.) results in increased shaft horsepower and fuel requirements due to added frictional resistance as the ship moves through the water.

A major constraint in maintaining/replacing these protective coatings is the serious shortage of naval drydock facilities. This constraint forces ships to remain afloat beyond the effective life of their antifouling coatings. The net resultant - increased fuel consumption - is certainly critical in today's era of markedly high fuel prices and diminishing petroleum supplies.

Thus, there exists a need for a marine coating system with an extended service life or for an economical means of lengthening the service lives of present day hull coating systems.

2. FINDINGS

- During FY 77 the active fleet will be comprised of 484 ships. Regular overhauls are planned for 105 of these ships, implying a five-year overhaul cycle in gross terms.
- The Navy is unable to overhaul the Fleet at the periodicity desired due to a shortage of drydocks among other things. It has been publicly stated that a large "backlog" of ship overhauls now exists.
- During Fiscal Year 1977, the active fleet will spend about three-fourths of its time not underway, a condition favorable for marine biota to make attachment to the hull.
- The established commercial/industrial base for the production of marine coatings imposes a constraint upon the final choice of a product for fleetwide service use. Although research and development efforts ought not be, and are not, fettered by such considerations, logistics planning decisions must reckon with the industrial supply base.
- The cost of facility modification, production equipment, personnel safety equipment, and waste disposal must be included when assessing the cost impact of a new coating.
- There are currently no prescribed standards which represent the maximum acceptable degrees of fouling on various ship types or specific portions of a ship's hull.
- The proper application of a marine coating system has perhaps as much effect upon the performance and service life of the system as does the

coating formulation itself. For this reason a considerable amount of effort should be devoted to assuring proper application of marine coatings in naval shipyards.

- There are environmental regulations which govern the manufacture, use, application and removal, and disposal of marine antifouling paints.
- The development work upon organometallic polymers (OMP's), which has been under way for several years, is comprehensive, orderly, and holds real promise for producing an antifouling coating with a service life span of at least five years. This work is nearing fruition.

3. STATE-OF-THE-ART

The state-of-the-art in anticorrosive coatings is far more advanced than present day technology in antifouling coatings. This gap is clearly evidenced by the difference in the effective service lives of the two types of coatings. Anticorrosive paints have proven effective for periods as long as seven years, while the maximum effective service life of antifouling paints is about three years. Thus, it is currently the antifouling component of a ship's underwater coating that limits the coating refurbishment/replacement cycle.

Since the number of marine coating systems is so large and since comparative studies have already been conducted on many of these systems, this report will address only the following five systems:

1) Navy Formula 150 (series)/Formula 121/63
2) SEAMASTER System (Jotun Baltimore Copper Paint Co.)
3) Self Polishing Copolymer (International Paint Co.)

4) "NO-FOUL" (Goodrich Corporation)

5) Navy Formula 1020A

4. GAPS IN TECHNOLOGY

- Marine Biology - There exists a need for a hull coating with a broad base toxin which would repel all types of marine biota for extended periods of time. A further understanding of the biology of marine fouling organisms might well be the key to developing such a coating.
- Coating Formulation - The technology gap most apparent in current marine coating formulations is the difference in the service lives of anticorrosive and antifouling paints.

  Resistance to the scouring action of high velocity seawater and the lack of a suitable accelerated testing device are two areas which also require attention.
- Application and Removal Processes - At this time, environmental regulations are constraining abrasive blast operations which are considered to be the most effective means of preparing a surface for new paint.

  A problem also arises relating to the disposal of spent abrasive containing organotin.

  Environmental regulations make limitations on spray painting operations. About 50% of the volume of paint used to coat a hull consist of volatile solvents which escape into the atmosphere during spray operations.

  There are currently no convenient means of coating the surfaces of a ship's hull which are masked by keel and side blocks while the vessel is in drydock.

5. ENVIRONMENTAL CONSIDERATIONS

Antifouling paint is a marine pesticide within the meaning of the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) 1975.

NAVSEC is taking action to register Navy antifouling paint formulas with the Environmental Protection Agency (EPA).

Residue from the industrial processes of application and removal of marine coatings contain pollutants within the meaning of the Federal Water Pollution Control Act.

Hydrocarbon solvents have already heavily impacted the marine coatings systems. The Navy's coatings engineering work force has been drawn away from its normal task of product development into revamping specifications for environmental reasons only. Environmental regulation of hydrocarbon emission from surface coating applications will probably bring additional constraints. More attention is being focused upon particulate matter in the worker's breathing zone rather than the ambient environment.

Two projects have been funded for FY 77 relating to hull cleaning. These are a CO_2 abrasive blaster and an automatic hull painter.

For all of these systems, Occupational Safety and Health Act (OSHA) requirements must be considered.

The costs of necessary personnel protective equipment and facilities must be included when deciding upon adoption of a specific coating.

6. PERSONNEL CONSIDERATIONS

Personnel considerations are important factors in the application and removal of marine coating systems. They include not only manpower requirements, but training and safety as well.

At present, replacement of a hull coating at a naval shipyard is accomplished by Shop 71 personnel generally over a period of several weeks during a ship's regular overhaul period. This type of work schedule permits the use of a minimum number of personnel engaged in work over a relatively long period of time. Replacement of a coating system in this manner has several disadvantages, which include the following:

- Abrasive blast operations generate large amounts of dust and often inhibit the performance of other exterior hull maintenance while the blasting is in progress.
- Shop 71 personnel are often hampered by interference from other shipyard tradesmen who are performing maintenance on both the exterior and the interior of the hull.
- Delays in the application process are sometimes encountered due to the non-availability of support services (e.g., crane service) at the times required.
- Painters and blasters must work around such obstacles as soil chutes and steam condensate drains.

The concept of "Pit-Stop" drydocking should be examined as a possible means of averting these disadvantages.

If the desired interval between a ship's regular overhauls is six years, for example, but the vessel's antifouling coating is effective for only three years, drydock the ship at the three-year point in a dock specifically designated for coating replacement and equipped accordingly. No other work would be performed during the "Pit-Stop" period.

It should be noted that if this process becomes standard procedure certain weapon removal operations would be required. If the ship is in a U.S. Naval Shipyard for less than six weeks only topside pyrotechnics need be removed. If the ship is in a commercial shipyard, all the magazines would have to be emptied, otherwise, the shipowner would have to pay the shipyard personnel hazardous duty pay.

Utilization of the "Pit-Stop" method offers many advantages including:

- Uniformity of the coating system is achieved by uninterrupted application over the entire hull.
- Considerable fuel savings by refurbishing a ship's antifouling hull coating at interim drydockings.

7. FACILITY/EQUIPMENT REQUIREMENTS

A large backlog of ship overhauls now exists.

The cost of complying with the prescribed safety precautions associated with organotin hull coating application and removal is substantial.

8. POLICY

The key requirement is for a marine antifouling coating to deter a wide spectrum of marine growth and to remain effective for an extended period.

The process of selection of a coating for service use is a decision process separate from RDT&E work. Among other things, this decision involves availability of raw materials, manufacturing capability of the commercial production base, industrial engineering for surface preparation and coating application, performance in service use and environmental constraints.

There are currently no prescribed standards which represent the maximum acceptable degree of fouling.

9. NEEDED RDT&E

The development work upon organometallic polymers (OMP's) which has been underway for several years is comprehensive, orderly, and holds real promise for producing an antifouling coating with a service life span of at least five years.

As an RDT&E task, examine the possibility of developing submarine coatings which provide camouflage and reduced sonar-reflectance.

As an RDT&E task, examine the possibility of developing underwater coatings to reduce structureborne radiated noise.

10. EFFECTIVENESS EVALUATION PLANS

As a minimum, maintain continuing liaison with and monitor the results of panel tests being conducted by the Coast Guard/Battelle Laboratories at Daytona Beach, Florida. Consider joint funding sponsorship of this valuable on-going work.

A Program Manager in the Naval Sea Systems Command should be designated as the executive agent to implement the recommendations of this Master Plan. His responsibilities should include the following:

- drafting a policy directive to be promulgated by OPNAV
- identifying fund resources in the budget necessary to foster these recommendations.
- ascertaining and tracking the progress ot the program.

Naval Shipboard underwater coating systems presently in use are being specified by "cookbook" type procurement specifications, that is, the exact ingredients and the quantity of each are spelled out. This procedure intrinsically fixes the service life of the coating, assuming that proper application techniques are followed.

11. NAVY FORMULA 150 SERIES/FORMULA 121/63

State-of-the-Art

These formulas constitute the Navy's most widely used hull coating systems. The formula 150 (series), the anticorrosive component of the system, is an epoxy-polyamide coating approved for use on underwater hulls, exterior topsides, bilges, tanks, and wet spaces. The series consists of the seven formulas listed below:

Formula	Description
150	Green Primer
151	Haze Gray No. 27
152	White
153	Black, RO 1.8
154	Dark Gray, RO 3.6
155	Dark Gray, RO 6
156	Red

Formula 121/63, the antifouling component of this coating system, is a red vinyl paint that is applied over the Formula 150 (series). The coating employs cuprous oxide as its toxic agent and has a maximum effective service life of about 3 years.

Advantages of Formula 150 (series)/Formula 121/63

- MILSPECS currently exist for both components of this system. A logistic chain for the manufacture, procurement, application, and removal of this system has already been established.
- From an environmental standpoint Formula 121/63, which utilizes cuprous oxide as its toxicant, poses no significant threat to man or the environment in the application, use or removal process. The product is currently registered with the EPA's Marine Pesticide Division.

- The total dry film thickness of the coating system (12 mils) is relatively small in comparison to other marine hull coatings, thereby contributing little weight to the displacement of the vessel.

Disadvantages of Formula 150 (series)/Formula 121/63

- Due to the chemical formulation of epoxy polyamides, each of the coatings in the Formula 150 series is supplied as two components which must be mixed, stirred, and allowed to stand for a prescribed period of time prior to their application. The potlife of the mixed components is 6 hours at 73°F.
- The service life of the antifouling coating is limited to three years under favorable conditions. Fouling has been known to occur in as short a period as 6 months, however, on ships operating in tropical waters.
- The cuprous oxide in Formula 129/63, the black antifouling topcoat, tends to turn green when used on the top side of submarines. This color change undermines the vessel's camouflage. The service life of this coating is considerably shorter than that of Formula 121/63.

Technology Gaps

The Formula 150 series has exhibited superlative anticorrosive protection for periods of up to 7 years. Formula 121/63 has proven effective for periods ranging from 18-36 months. The major technology gap apparent in this system is the limited service life of the vinyl antifouling coating.

A technology gap apparent not only in this system, but in other systems as well, is the inability of the coating to stand up under conditions of high velocity water flow.

Needed RDT&E

The need for long life antifouling hull coatings that are compatible with our environment is recognized world wide. The U.S. Government, as well as many foreign governments and private industry, is presently conducting research to develop such coatings.

Environmental Considerations

The antifouling component of the Navy's hull coating system employs cuprous oxide as its toxic agent. Cuprous oxide is relatively harmless to man and the environment in its application, use or removal.

12. SEAMASTER SYSTEM

State-of-the-Art

The SEAMASTER System was developed by the Norwegian paint manufacturer JOTUN in consultation with the Ship Research Institute of Norway. The system, which is categorized generically as a cholorinated rubber, is comprised of the following coats:

- one 0.6-0.8 mil coat of Securit Zinc-Rich Shop Primer
- four 4 mil coats of Vinylguard
- four 3 mil coats of SEAMASTER Antifouling on side bottom
- two 3 mil coats of SEAMASTER on flat bottom area

The effective service life of the SEAMASTER System in commercial applications is advertised to be 4 to 5 years, requiring three or four waterborne reactivations of the antifouling coating during that time period.

Advantages of SEAMASTER

- The system's four/five year service life offers extended intervals between drydockings.
- The system utilizes a form of copper as its toxic agent, as does the U.S. Navy's present hull coating system. Copper is mined domestically and is available at a relatively low price.
- The JOTUN Marine Coatings Company has 22 distributors in the U.S., located on all coasts.

Disadvantages of SEAMASTER

- Precisely controlled paint application is required for the SEAMASTER System to be effective. The manufacturer recommends that "plenty" of time be allowed for drying between coats.
- Because the product is proprietary and only available from a single manufacturer, the use of competitive bidding in the procurement process would be precluded.
- The SEAMASTER System is applied to a substantially greater thickness than the Navy's present coating system, resulting in increased displacement of the vessel.
- The cost per gallon of the product is significantly higher than the cost per gallon of the Navy's present hull coating system.

- Besides being expensive and inconvenient, the coating reactivation process tends to increase the roughness of the coating system, and in some instances, when not properly carried out, may even result in damage to the anticorrosive coating.

Technology Gaps

A major factor affecting the service life of the SEAMASTER System is the quality of underwater brushing achieved during each reactivation period. Underwater brushing equipment and techniques have certain limitations which restrict it from performing an effective brushing/reactivation of the entire underwater hull.

Needed RDT&E

RDT&E efforts are required to develop an automated underwater brushing apparatus capable of cleaning the entire submerged portion of the hull without damaging the coating system.

Environmental Considerations

The SEAMASTER System employs cuprous oxide as its toxic agent. Since no regulations currently exist prohibiting the waterborne brushing of ship's hulls in navigable waters, the use of the SEAMASTER System poses no problems at the present time.

13. SELF-POLISHING COPOLYMER

State-of-the-Art

The Marine Coatings Division of the International Paint Company has recently introduced a three coat Self-Polishing Copolymer (SPC) Antifouling Paint System. The System provides antifouling protection only, and consequently, must be applied over an anticorrosive coating. According to the manufacturer, the System is designed not only to give extended freedom from fouling for two years or more, but also to contribute significantly to the reduction of hull surface roughness by its built-in self-polishing action.

A typical SPC application would consist of the following coats:

1st coat Red	3 mils
2nd coat Gray	4 mils
3rd coat White	4 mils

Unfortunately, SPC is not yet licensed for sale in the United States.

Advantages of the SPC Antifouling System

- The SPC System not only prevents fouling but also reduces hull surface roughness.
- The System requires no type of cleaning or reactivation during its service life.
- The SPC antifouling coating could be used in conjunction with the Navy's formula 150 (series) anticorrosive coating which has already proven to be extremely effective.

- Since the SPC coating maintains itself in a highly polished state during its entire service life, no abrasive blasting is required prior to renewal of coating.

Disadvantages of the Self-Polishing Copolymer

- Though advertised to be two years or more, the service life of SPC has not been independently verified, at least to date, for a Navy application which requires the ship to spend a majority of time in port. Extended in-port periods might result in depletion of the antifouling toxicant at the surface of the paint since there is no water flow to wear away the depleted paint surface and expose new layers of toxin.
- SPC utilizes tributyltin oxide as its biocide, which has a relatively high level of human toxicity. Tin, the raw material from which the biocide is produced, must be obtained from foreign sources.
- Procurement of the product for fleetwide use would require an exemption from Armed Services Procurement regulations (ASPR) since the product is manufactured by only one proprietary company.
- The produce is not yet available for sale in the United States.
- Though the product may be applied to the hull appendages, it was not specifically designed for this type of use and, consequently, will not perform as well in these applications.

Technology Gaps

The SPC formulation will not adhere properly to all types of anti-corrosive undercoats. This has proven to be the case with the Navy's Formula 150 (series) anticorrosive coating.

Needed RDT&E

The service life of SPC is said to be directly proportional to the applied film thickness. Obviously, there are physical and practical limitations of the thickness to which the coating system can be applied. RDT&E efforts are needed to alter the SPC formulation so as to reduce the rate of wear on the coating, while at the same time, maintaining the system's superb antifouling properties.

Environmental Considerations

The SPC coating employs tributyltin oxide (TBTO) as its toxic agent. Though highly effective as a marine biocide, TBTO offers the disadvantage of being toxic to humans as well. The use of this product, therefore, brings with it certain precautionary requirements during the applications and removal of the paint systems and disposal of the wastes from these processes.

14. GOODRICH "NO-FOUL"

State-of-the-Art

"NO-FOUL" is a proprietary product manufactured by the B. F. Goodrich

Company. It is an elastomeric sheet (80 mils thick) which is attached by a proprietary adhesive system to the underwater portion of steel, aluminum or wooden hulled vessels. On a test conducted by Battelle Columbus Laboratories and the U.S. Coast Guard, the "NO-FOUL" system received a rating of "outstanding" with a projected service life of up to 10 years.

Advantages of Goodrich "NO-FOUL"

- The product offers a possibility of up to ten years' resistance to corrosion and fouling.

Disadvantages of Goodrich "NO-FOUL"

- The initial cost of the material is relatively high.
- The Goodrich Company, which is the only source of the product, manufactures it on a proprietary basis.
- The application of "NO-FOUL" is a laborious process since the product is sold in rolls and must be measured, cut, and then attached to the hull by an adhesive.
- Relative humidity and temperature are critical factors in the application process. The temperature range for applying "NO-FOUL" is 50-90^{o}F, with the relative humidity to be controlled within 5 units of the temperature.
- Problems have been experienced by the Navy in attaining good adhesion of the elastomeric sheet to sonar dome surfaces and in repairing damaged portions of the covering.

- Because of its low shear resistance, "NO-FOUL" is susceptible to damage by camels, balks, etc., if applied in the vicinity of the water line.
- "NO-FOUL" is difficult to remove from the substrate to which it was applied.

15. NAVY FORMULA 1020A

State-of-the-Art

Navy Formula 1020A, commonly referred to as "organotin paint", is a black antifouling coating which was developed by the Navy in the early 1970's. Its intended use is for boottopping on surface ships and for exterior topside surfaces on submarines where camouflage is desired.

The Commander, Naval Sea Systems Command, restricted the use of organotin paints on all Navy submarines in November 1975. Use of the product was limited to the following applications:

- Maintenance of those portions of submarine hulls already painted with Formula 1020A.
- Submarines in overhaul for which organotin paint had already been ordered.

Thus, Formula 1020A is in very limited use in the Fleet today.

Advantages of Formula 1020A

- The paint appears to offer a substantially longer service life than the Navy's current black antifouling coating (Formula 129/63).

- Formula 1020A is compatible with the Navy's current Formula 150 (series) anticorrosive undercoating.
- The product can be used on aluminum as well as steel-hulled vessels.

Disadvantages of Formula 1020A

- Since the coating contains an organotin biocide, the rigorous and costly safety precautions prescribed in NAVSHIPS NOTICE 9190 of 28 May 74 must be observed during the application and removal processes.
- Disposal of the toxic waste materials generated from the application and removal processes is extremely costly.
- Tin, the metal from which the antifouling toxicant is produced, must be imported from foreign sources.
- Softening of the coating during its service life hampers serviceability (i.e., patch painting of damaged areas).

Technology Gaps

Technology gaps in this system and other coating systems containing organotin toxic lie in the area of worker and environmental protection during the application, removal, and waste disposal processes.

Needed RDT&E

R&D efforts are currently underway at DTNSRDC, Annapolis, to develop a means of detoxifying both the liquid and solid wastes generated during the application and removal of organotin coatings.

Environmental Considerations

Unlike the Navy's current copper-based antifouling paints, Formula 1020A utilizes tributyltin oxide (TBTO) and tributyltin fluoride (TBTF) as its antifouling agents. Both of these substances are highly toxic to marine growth and relatively hazardous to humans.

SUMMARY

NON-COATING PROTECTIVE SYSTEMS: (APPENDIX B)

1. INTRODUCTION

Ship hull fouling and related corrosion and hull surface roughening increases fuel consumption and ship's power requirements. This in turn imposes high hull maintenance costs. Fouling and corrosion of sea water cooling systems causes additional fuel consumption. Due to environmental and safety regulations and the Navy's operational needs, it has become increasingly difficult to select cost effective systems and equipment to control fouling and corrosion.

Biological fouling and deterioration of materials used in marine service account for a high annual maintenance expenditure by the Navy. More than 215 million dollars in 1974 was lost due to the fouling-related deterioration of wood docks and piers and fouling growth on ships' hulls alone.

The Navy annually prepares 10 million square feet of ships' hull surface for antifoulant paints. The cost of labor and materials exclusive of drydocking costs is $15 million. The largest number of active ships in the U.S. Fleet consists of submarines and destroyers. These ships, because of service conditions, require the most frequent antifouling maintenance. This study on non-coating protective systems reviews the state-of-the-art of systems and concepts which will provide alternate methods of preventing fouling/corrosion of seawater systems and ship hull surfaces.

This study involves:

- Establishing the state-of-the-art concepts which can be immediately applied.
- Consideration of the environmental impact of different systems.
- Identifying necessary future RDT&E.
- Recommending effectiveness evaluation and progress tracking plans.

Existing underwater body surface protection systems such as anti-corrosion and antifouling hull coatings are subject to in-service degradation and provide limited protection. It is necessary to have supplementary protective systems as a backup to the coating systems.

The problem is to find anticorrosion/antifouling protection systems which will allow, in a cost-effective manner, at least 5 year drydocking intervals, and provide effective corrosion and fouling protection throughout the life of the ship.

The purpose of this study is to evaluate systems which provide cost-effective anticorrosion and antifouling protection, within constraints, to Navy ship underwater hull surfaces.

Corrosion

Corrosion of metals is an electrochemical process similar to the operation of a wet cell battery. In the corrosion process an oxidation reaction occurs at the anodic hull from which metal atoms are ionized and go into solution leaving behind an electron surplus. At the same time a reduction reaction occurs which transfers ions to the cathodic propellers or hull appendages.

Protective measures are taken to prevent ship hull corrosion. The obvious solution is to insulate the hull with some sort of coating so that no current can flow. These hull coatings are most frequently paints. Coatings become scratched, broken or scraped, or become absorbent during normal operations. This causes a loss of effectiveness over a period of time. Consequently, a back-up system is required to supplement the protection provided by hull coatings.

Since 1966, most new U.S. Navy ships have been designed and many others have been backfitted with Impressed Current Cathodic Protection (ICCP) systems for electrochemical corrosion protection. SHIPALTS exist to install ICCP systems on practically all remaining Navy ships. This system, which replaces the galvanic anode system, has advantages of low weight, low hull flow obstruction profile, protective current capacity for all ship operating conditions, coating losses, stray current (galvanic anode systems protect only at ship standstill), operation for over ten years' period without drydocking (comparable three year galvanic anode).

Fouling

Surfaces continually exposed to seawater soon become covered with animal and plant organisms called fouling. Fouling is a concern because it increases hydrodynamic drag, clogs piping, increases weight, and may increase corrosion of metals. Nearly 2000 species of animals and plants have been reported to make up fouling on man-made structures.

The organisms found on a submerged surface depend upon many factors; the speed of water relative to the body, the season of the year, the geographic location, the depth, the texture of the surface and the effects of light and gravity. It is best to run tests of antifouling measures in tropical regions where seasonal variations are at a minimum and reproduction and growth is likely to take place all year long.

Fouling organisms often cause corrosion of metals to which they are attached by bringing about depolarization of the metal's surface as a result of their metabolic processes. Organisms may injure paint meant to protect structures from corrosion and cause pitting. The worst offenders are barnacles, mussels, and oysters.

The amount of fouling accumulated on ships depends upon the length of time that they spend in port, together with the location of the port. Ships which use a freshwater port have the advantage of few fouling organisms. Those freshwater fouling organisms that do exist are mostly plants.

The most important effect of fouling on ships is an increase in drag due to an increase of surface roughness.

The decrease in propeller efficiency due to fouling can be quite substantial. Tests have shown that fouling increases fuel consumption and reduces propeller efficiency.

Environmental Considerations

The Department of the Navy has established a philosophy of protection of the environment and conservation of natural resources.

All facilities owned by, or leased to, the Federal Government must be designed, operated, maintained and monitored to conform to applicable air, water, and noise standards. Federal facilities are not subject to state pollution programs permit requirements by a U.S. Supreme Court ruling on 7 January 1976; however, these facilities are subject to federal regulations.

With respect to anticorrosion and antifouling systems, the areas of environmental concern are limited to liquids, solids, or gases which would be discharged into the atmosphere or into navigable waters. Listed substances are designated as hazardous on the basis of toxicological properties of one component ion or group.

2. FINDINGS

There are few non-coating, antifouling and anticorrosion systems which have reached a level of full operational readiness. The term "full operational readiness" must be viewed in a relative sense, since even the impressed current cathodic protection (ICCP) system, which is on a number of Navy ships, has operational anomalies.

The impressed current cathodic corrosion protection system, and the galvanized anode installation for corrosion protection are considered to be operationally ready for Fleet use. A seawater antifouling system known as the Engelhard electrolytic hypochlorinator has been used on commercial ships successfully, but is considered to be in an "evaluation" status from a Navy viewpoint. This system has not been fully evaluated for Navy use, but operational readiness will be determined only after shipboard tests have been completed. No other non-coating supplementary antifouling systems are known to be used as operational systems by the Navy.

Impressed Current Cathodic Protection (ICCP) Systems on Steel Hulled Ships.

The impressed current cathodic protection systems have been providing excellent corrosion protection on Navy Fleet ships.

Initially, the impressed current system is more costly to produce and install than sacrificial anodes and may require maintenance during its life. It is flexible, lightweight and automatically variable in current output to react to varying conditions of speed, salinity, temperature and increased bare metal exposure.

The impressed current system is considered to be the lowest cost option for cathodic protection and is installed on approximately 1/3 of the U.S. Navy surface ships. A SHIPALT exists for most active surface ships and is scheduled for accomplishment during upcoming regular shipyard overhauls.

NON-COATING PROTECTIVE SYSTEMS — SUMMARY

Manufacturers of impressed current cathodic protection systems are Engelhard Systems, Engelhard Industries Division, Newark, New Jersey; Norton Corrosion Limited, Inc., Woodinville, Washington; Lockheed Marine, Ontario, California; and Morgan Berkley and Company, Ltd., Winchester, Hants., England. These components provide impressed current cathodic protection systems for shipboard application to a worldwide market.

Wilson, Watson International, Inc., has disclosed their development of a new anode concept which overcomes some of the technological problems and costs associated with the manufacturing of platinum clad anodes. Their anode, the DSA (Dimensionally Stabilized Anode), is a combination of oxides of titanium and ruthenium applied to a titanium substrate and baked above 700°C for a precise period of time. These films have poor electrical conductivity, but have a high surface area which overcomes the resistance problems and enhances their electrochemical activity. This system also has a designed-in feature which prevents over-protection of the ship hull in the event of reference cell failure. Further development and the operational evaluation should be monitored for applicability in corrosion protection systems.

Further development is needed for the use of this type system on submarine hulls. Improved pressure hull stuffing glands need to be developed for anode mounting. Potential hydrogen embrittlement, caused by the system's cathodes, may occur in High Tensile Steel (HTS). Knowledge is lacking in regard to the impact of impressed current ripple on the fire control and sonar systems, and electromagnetic (EM) signature potential. Current ripple is of 30 milliwatts magnitude at the anode even with a passive filter installed in the system.

Impressed current cathodic protection systems are being installed aboard 637 class submarines for evaluation. The anodes have been mounted on the exterior of ballast tanks where it is not necessary to meet submarine SUBSAFE requirements.

At present, the environmental impact by the compounds released into the water by these systems is of little concern to the EPA. Only two people are required part-time for operation and maintenance. These systems are easily maintained by one person with only hand tools and voltohmeter.

ICCP of Aluminum Hulled Ships

The use of impressed current and sacrificial anodes on weight-critical craft which are constructed of aluminum alloys, and of HTS components creates difficulty in positioning anodes relative to the aluminum and steel members. Aluminum hulls can be driven highly cathodic when high current densities are required to polarize the HTS materials to the corrosion potential of the aluminum. Too much current causes an alkaline condition that is corrosive to aluminum. This over-protection results in rapid deterioration of the metal.

ICCP of Seawater Piping Systems

Cathodic protection levels established within seawater piping systems have been satisfactory. Further development, relative to the proper anode placement for maximum protection, is needed.

Pulsed Direct Current (DC) Cathodic Protection

Pulsed ICCP systems under development by Shell Development Division offer a number of desirable characteristics among which are very low ripple and no Radio Frequency Interference (RFI) on anode output, plus low loss of power to capacitate energy. Current evaluation of these systems is being made on off-shore oil platforms. As presently designed, the systems emanate a 20-volt level which is unacceptable for Navy ship use.

Ship Hull Corrosion and Fouling Prevention Using Copper Nickel Clad Materials

Copper-nickel clad hull structural plate material development, offering apparent substantial corrosion and fouling savings, is in the hull fabrication state of development.

The International Nickel Company, Copper Development Association, E. I. DuPont, and Lukens Steel Company have been jointly developing copper-nickel clad steel plate for ship hull construction. Preliminary tests involving the COPPER MARINER were encouraging. The performance of the 90-10 copper-nickel hull over two and one-half years showed significant savings as compared to a steel-hulled sister ship. The savings were (1) reduced fuel bills; (2) higher speeds; (3) no corrosive deterioration of the hull material; (4) no expenses for periodic haulout, scraping and painting of the hull; and (5) more time at sea. Reported percentage improvements were:

- Speed Improvement - 15 percent
- Fuel Consumption Decrease by 15 percent

The techniques for developing the copper-nickel clad by E. I. DuPont and Lukens Steel Company are explosive bonding and roll bonding. Both of these techniques result in an electron-sharing bond of the copper-nickel with substrate steel plate. Not yet developed as a process, the preparation of a composite slab by either casting or diffusion bonding would be expected to yield a clad plate that is less expensive than a corresponding plate produced by hot roll bonding from a pack.

Adhesive techniques and spot welding are other methods of cladding, though no reliable data is available on service in the marine environment.

Galvanic Anode Hull Protection

Galvanic anodes, primarily zinc, are still in use on submarine and surface ships for hull protection. They are being replaced by impressed current systems on surface ship hulls. Development efforts required include the preparation of specifications for aluminum anodes and the development of environmentally acceptable anode materials.

Stray Current Corrosion of Steel

Stray current corrosion has been of concern to the Navy over the past few years. Corrosion caused by improper grounding during welding has been eliminated in at least some of the cases. However, sources of the currents in many instances have not been identified. Field studies showed that stray D.C. currents existed in some Navy berthing sites. Some berthing sites have D.C. driven electric cranes which may cause stray currents to enter into the water, and pass from ship to ship through the water.

3. FOULING PROTECTION SYSTEM

Hull roughening caused by corrosion is cumulative and occurs over a long period of time. Fouling, on the other hand, causes a non-cumulative roughening, from the standpoint that it can be completely removed. The short term impact on speed loss of fouling is much more costly than that caused by corrosion.

Sonar Dome Fouling Control

The state-of-the-art currently consists of a cell injection system developed by Engelhard Systems. The system uses a chlorine generator and a net to hold the sodium hypochlorite near the dome. This system has not been installed for evaluation.

Fouling Control Via Chlorine Distribution in Seawater Piping System

Fouling control of seawater piping systems has been largely a matter of designing the piping systems to provide for seawater velocities in excess of 3 ft./sec., which exceeds the velocity at which sessile organisms can adhere. Engelhard electrolytic hypochlorinator systems (CHLOROPAC) are used in numerous landbased and commercial shipboard installations. This system injects 0.5 parts per million (ppm) of sodium hypochlorite generated through electrolytic decomposition of seawater. This type of system is on one U.S. Military Sealift Command Ship, the USNS WHEELING. It is planned to evaluate a shipboard installation on an FF-1052 class ship. This system is simple, relatively inexpensive and successful in preventing fouling in seachests.

The "TOXION TWO" system is produced by F. A. Hughes and Company Limited in Epsom, Surrey, England. A tin-based antifoulant agent is reportedly used with excellent results in European shipboard seawater systems. This system has been used successfully with an antifoulant injection level of 0.003 ppm. The singular organic tin compound, stannous flouride, listed in the EPA Hazardous Substances List is allowed to be placed into navigable waters up to 100 ppm. This system warrants U.S. evaluation for potential Navy use.

Electrolyzed Seawater System

This system to prevent hull fouling was developed by Mitsubishi Heavy Industries, Ltd., Nagasaki, Japan. The system electrolytically develops chlorine from seawater and after combining the chlorine-laden seawater with pressurized air, delivers the mixture through nozzle pipes fitted to the bilge parts of the hull. The mixture rises up to the surface along the ship's hull plates as a bubble screen type flow.

The antifouling effect of this system has been confirmed on a 50,000 ton ore carrier.

The current designs are estimated to have an 8 to 10 year service life with minimal maintenance.

CEPI-COMAV Magnetic Scale Prevention Device

The "CEPI-COMAV", developed by S.A. Epuro Company, Antwerp, Belgium, is reportedly used on over 100 Swedish and 1000 Soviet seagoing ships. It is claimed to prevent calcium carbonate scale deposits by magnetically converting dissolved salts (principally calcium carbonate) from the calcite form to the aragonite form (a powdery substance which will not form scale as calcite does). The unit requires no power input; it is designed for direct insertion in a piping system with minimal maintenance. Ship degaussing effects on the magnets in the CEPI units are not known. The magnetic influence is destroyed in components which have a high heat transfer rate. Also, flow of water through pumping elements degrades the magnetic effect, such that placement in the system becomes important.

Ultrasonic Hull Vibration Techniques of Preventing Fouling

The Soviets use magnetostriction properties of hull transducers to obtain ultrasonic antifouling hull protection. The Soviet maritime fleet now has about 20 ships equipped with this system. Despite the fact that this system has been in use for over 10 years, there are still no data on the distribution of high-frequency vibrations over hull structures. The objective of these studies was to check the efficiency of ultrasonic antifouling protection and study vibration damping in the hull by measuring high-frequency vibrations on a KRASNOGRAD-class ship.

AQUATRON Scale and Algae Elimination System

The American AQUATRON System, developed by the Delta Tech Corporation, Dothan, Alabama, is currently in use by U.S. industry for the removal and prevention of scale (deposits of calcium, magnesium, and other salts) and algae in both fresh and salt water handling systems. This system utilizes a solid-state microcomputer controlled device to raise the water molecule electrons to higher energy states. The resulting ionized water has the ability to transfer this energy to dissolved carbonates, sulfates, etc., thereby preventing these salts from precipitating on piping walls as scale. Another benefit of this ionized water is that it fatally disrupts the metabolic process of simple organisms such as algae, slimes, etc., by interfering with their nutrient absorbing capabilities. This results in the destruction of a wide range of lower order waterborne organisms, without the use of chemical toxins or water temperature changes. From an environmental standpoint, it should be noted that artificially ionized water reverts back to its natural state after approximately 14 hours.

SUMMARY

APPENDIX C: FOULING DIAGNOSTICS AND INSPECTION METHODS

1. INTRODUCTION

There is conclusive proof that hull appendage and propeller fouling has a significant deleterious effect on ship fuel consumption and speed. Dramatic increases in ship fuel costs combined with the need to maximize the operating range of Navy ships make it urgent that fouling diagnostic methods be improved.

In addition, development of effective fouling diagnostic and inspection methods will determine optimum time and conditions for cleaning the ship's underwater hull. The specific objective of this study is to develop cost-effective methods that will alleviate the necessity for dry-docking ships for 'bottom cleaning jobs' for as long as 5 to 7 years. During this period, the degree of fouling is not to exceed the level at which ship speed and fuel consumption are significantly affected.

Several methods are used as coarse indicators of fouling, but there are no well-developed fouling diagnostic techniques currently used on a consistent basis. The one fouling diagnostic method currently being used, from which only a gross evaluation of the effect of fouling on ships' power can be derived, is diver inspection of the hull. Such underwater inspection techniques are highly subjective and carried out by visual inspection reinforced by some photography and television. In addition to being subjective, there is no precision in 'mapping' locations of fouling. Water conditions (visibility, temperature, current) are often poor, inspection rate is slow, and experienced inspectors are few in number. Also, correlation factors relating to the severity, type, location, distribution and time-rate of fouling growth are needed in order to arrive at sound decisions as to when, how, and where to remove fouling. This should also include consideration of factors such as cost of cleaning, cost of paint, paint life and fuel savings.

2. FOULING DIAGNOSTIC FINDINGS

Formal fouling diagnostic methods and procedures have not been developed for either Naval or commercial use. The criteria for fouling diagnosis that do exist result largely from the efforts of companies involved in hull cleaning. They have shown the ship operators that costs can be saved by cleaning the ship while waterborne. Ship classification societies are also conducting inspections with ships waterborne.

The Navy's Shipboard Energy Conservation R&D Program, being pursued by David W. Taylor Naval Ship Research and Development Center (DTNSRDC) in the areas of hull cleaning and formulation of antifouling coatings, is closely related to the development of fouling diagnostic and inspection methods discussed herein. The hull cleaning portion of the DTNSRDC Code 2705 Energy Conservation Program, which commenced in FY-1975, is a four year program terminating in FY-1978. The elements of this program relating to fouling diagnostics and inspection methods are basically those involving the determination of 'when' and 'how' to clean the underwater hull and appendages of ships. The effect is summarized as follows:

- Evaluation of commercially available hull cleaning methods including assistance to Fleet Commanders in support of hull cleaning efforts.
- Development of cleaning methods for Navy ships where gaps exist.
- Laboratory evaluation of paint wear with cleaning.
- Conducting, by sea trials, economic trade-off analysis between cost

of cleaning and fuel costs associated with fouling (hull cleaning frequency determination).

- Determination by sea trials of long term impact of repetitious cleaning.
- Development of Fleet instruction on 'when' and 'how' to clean.

As part of the Energy Conservation Program, research leading to the development of a fouling diagnostic system involves torsionmeters, Sperry Doppler speed logs and other monitors for propulsion plant parameters. The current emphasis is on verifying the correlation between shaft horsepower as measured by a torsionmeter and first stage H.P. turbine shell pressure. Results to date have been encouraging. It may be that first stage H.P. turbine shell pressure correlation with ship speed will prove to be an important diagnostic technique for measuring fouling performance degradation.

In the event test results fail to verify high correlation over time between SHP and first stage H.P. turbine shell pressure, the utilization of a torsionmeter and/or other instrumentation will have to be considered as basic diagnostic tools. The state-of-the-art of torsionmeters is well advanced with thousands of units in use worldwide, many of which are on ships, including approximately 28 currently aboard U.S. Navy ships. Most of them were installed for purposes other than for fouling diagnostics. The unit cost of torsionmeters for Navy shipboard application ranges between $11,000 and $40,000, with installation costs running between

$8,000 and $15,000 per unit. Therefore, the use of torsionmeters solely as a diagnostic method will involve a considerable expense. Torsionmeters should not be procured and installed on ships solely for use as a fouling diagnostic tool unless DTNSRDC Programs show conclusively that no other less costly method will be available in the near furture.

An accurate ship speed measuring device/method is required to complement any power measuring device (torsionmeter, first stage H.P. turbine shell pressure, etc.) in forming a fouling diagnostic system. Essentially, all speed logs on Navy ships are the electro-magnetic (E.M.) type which, theoretically, should be very accurate. However, many ships experience accuracy errors ranging up to 5% or more.

Speed logs exist which may prove to have the required degree of accuracy for fouling diagnostic purposes. The Sperry Doppler SRD-301 currently being evaluated by DTNSRDC Code 2705 Energy Conservation program appears to provide such accuracy. It is possible that a properly calibrated EM log may have a useful speed range within which the degree of accuracy is high enough for fouling diagnostic purposes. This has yet to be explored. The Westinghouse ACULOG has the potential to be very accurate; however, the elements external to the ship's hull consist of three sword-like devices which in turn are subject to deterioration by fouling and damage.

Very few measured ranges, readily accessible to Fleet units, exist which could be traversed to determine accurate ship's speed through the water. Also, very few sites for such visual ranges exist, especially for ships operating out of Navy ports in the southeastern section of the U.S. Ships equipped with torsionmeters should be required to traverse existing measured ranges (e.g., Guantanamo Bay, Cuba; Roosevelt Roads, P.R.; Barbers Point, Oahu, etc.) when in the vicinity of such ranges. SHP and other appropriate data should be recorded and sent to DTNSRDC for evaluation and analysis.

A minimum water depth of 150 feet is required for FF-1052 class and smaller ships. Carriers and other deep draft ships will require greater water depth to avoid bottom effects on power tracking. This minimum water depth requirement would place the ship about 25 miles off the eastern coastline and out of visual range of the range markers.

Several other techniques have potential as fouling diagnostic methods. However, they presently exist either in concept form or as rough diagnostic indicators, and would require developmental effort in varying degrees. These concepts and techniques may be summarized as follows:

- Electrical Measurements of Hull Coating - Measurement of the electrical resistance of hull coating through impressed current cathodic protection system instrumentation provides a rough indication of the condition of the hull coating at the present time. NAVSEC 6101C is studying this technique.
- Temperature/Flow Differential Monitoring - Monitoring flow rates and temperature differentials in the seawater side of heat

exchangers and other seawater piping systems offers a prospect of diagnosing fouling sea chests and associated piping systems.

- Propulsion Parameter Correlation - In addition to first stage H.P. turbine shell pressure as part of a fouling diagnostic system, other propulsion plant parameters may also prove valuable.
- Measured Distance at Constant RPM - This concept finds limited use in merchant ships for fouling diagnosis. The distance used is either the port to port distance or the distance between navigational fixes. A principal disadvantage of this method is the limited availability of measured mile ranges convenient to Navy operating areas. It is possible, however, to use navigational satellites for obtaining real time fixes over long distances. For this information to be accurate, it is necessary to compute out all effects of wind, sea state, ship pitch, etc.
- Noise Measurement - Noise measurements are routinely made by submarines and surface ships to ensure that they are not radiating excessive noise. Noise levels are being used in the submarine community as an indication of excessive fouling and for identifying other noise producing sources. The equipment and technology are presently available to obtain ship noise signatures. However, a correlation is required between noise level, frequency and degree of fouling.
- Time Indexing - Most fouling diagnostic systems in use today are based on time. Several commercial companies clean the ship bottom

after nine months out of drydock and then every three to four months thereafter. Other schemes of indexing could yield more accuracy. A fouling point system could be implemented now using arbitrary standards such as 1 point for a day in a known fouling port, 1/8 point when underway at more than 15 knots, etc. An accumulation of some numbers of points could then be an indication of the need for cleaning.

3. UNDERWATER INSPECTION FINDINGS

The discussion of inspection methods is associated with two functional types of inspection: (1) inspection as a fouling diagnostic method, and (2) inspection of the physical integrity or seaworthiness of Navy ship hulls. The following are specific findings determined by review of current underwater inspection methods:

- Divers who conduct underwater hull inspections have received little or no training in fouling or hull integrity inspections.
- The Underwater Work Techniques Manual provides little guidance for conducting underwater inspections.
- No standards exist to aid divers in diagnosing fouling type and quantification thereof.
- No standardization procedures for conducting underwater inspections exist, although the Underwater Work Techniques Manual contains a suggested report format. The quality of underwater inspection varies from Command to Command.

FOULING DIAGNOSTICS AND INSPECTION METHODS SUMMARY

- No standard diver inspection tools exist. Most divers have assembled individual assortments of tools that are relatively effective.
- The Navy has virtually no capability for conducting Non-Destructive Testing (NDT) inspections with the ship waterborne. Some land-based equipment which can utilize a long cable between the sensor and the readout devices are in use.
- Several commercial companies in the field of underwater inspection use the full range of NDT equipment.
- Keel hauling lines are the most widespread hull/swimmer location device employed by Navy divers.
- Acoustic pinger location devices are being developed and should become available to Navy divers. Navy Coastal Systems Laboratory (NCSL) is conducting efforts on such a system.
- U.S. Navy divers are trained from almost any rating group. In the Royal Navy (British), "Diver" is a rate and "Underwater Inspection" is a functional part of the rate.
- Navy divers do not have standard work boats from which to work. Adaptions of several existing available boat types have been made, but few are equipped for effective operation.
- COMNAVSEAINST 9597.1 contains a listing of approved diver support equipment. Few fleet diving units have all the essential equipments listed because funding for initial outfitting is generally from the user's O&MN funds, which are always in short supply. As new and better tools are developed, they frequently do not become

available to the diver because funds are not specifically designated for such purposes.

- There are no measurement instruments available to Navy divers for underwater inspection purposes to determine the following:

  - Crack detection
  - Leak detection
  - Fouling level
  - Corrosion deterioration
  - Liquid level, oil/water
  - Surface profile or roughness
  - Coating evaluation

- Commercial divers are used as observers in many cases where a problem is suspected; but for required ship inspections, trained surveyors are used. Some inspections are being conducted with the inspector/surveyor topside observing a closed circuit TV monitor from diver held or remotely controlled cameras. Some companies are considering training their qualified inspector/surveyors as divers.

- Clear-field underwater viewing devices are in limited use in commercial diving operations but none have been officially designated for Navy use.

- NCSL has recently been assigned responsibility for development, test and evaluation of diver inspection tools. Funding at NCSL for diver inspection tools is currently exploratory development money. T&E of the most promising commercially available equipment should be included.

- Ship underwater hull maintenance requirements have lacked management and funding support. The bulk of the required RDT&E effort relating to underwater hull inspections is deemed to be in the Engineering Development and Operational Systems Development categories. Most of the past funding for inspection related efforts has been largely from Exploratory Development and Advanced Development categories.

4. EFFECTIVENESS EVALUATION PLANS

Effectiveness evaluation plans for both fouling diagnostics and underwater hull integrity inspection systems will be based primarily on empirical data and feedback. It is recommended that a comparative analysis be used to evaluate the effectiveness of the fouling diagnostic system.

The most objective criterion by which to evaluate the effectiveness of the underwater hull integrity inspection process is to conduct and document such an inspection immediately prior to a regularly scheduled drydocking of a ship. The comparative analysis of the pre- and post-drydocking inspections provides an excellent evaluation of the effectiveness of the underwater hull inspection.

5. DEVELOPMENT PROCESS TRACKING PLAN

There are three essential elements to consider in establishing a development progress tracking plan. These elements comprise a monitoring center, a communications network and a reporting system.

The function of the monitoring center is to track and review the programs being followed, with respect to both the administrative and the technical activities of the program.

The communications network is needed to provide input data to the monitoring center, as well as feedback to the performing activities.

The reporting system function is to keep management informed of overall program status and progress and to disseminate information to performing activities.

The monitoring center, communication network and reporting system should be established first in order to begin the integration of ongoing efforts into the overall program.

6. POLICY AND ORGANIZATION RECOMMENDATIONS

Effective implementation of the foregoing recommendations requires the establishment of an appropriately structured organization having well-defined lines of control. The key to such an organization is a strong program manager and charter in NAVSEA with appropriate OPNAV sponsorship. The recommended structure required to direct an integrated hull husbandry program includes the following:

- Program Sponsor in CNO

- Program Manager in NAVSEA
- Advisory Committee
- Task Groups
- Industry Support

7. FOULING DIAGNOSIS DISCUSSION

The current technology used in many fouling diagnostic concepts is based on the fact that hull resistance increases as surface roughness increases. The problem then becomes one of measuring the change in hull resistance as the ship becomes fouled. One way to assess the condition of the hull is to monitor the time and fuel rate usage as a ship traverses a fixed and known distance under reproducible conditions. The use of torsionmeters in conjunction with ship speed is another method that gives an indication of the increased shaft horsepower necessary to maintain ship speed as a function of time. The problem faced in this method is that any fouling of the propeller cannot be separated from the effects of hull fouling.

- Torsionmeters. The shaft horsepower developed by a ship can be conveniently obtained by the use of an appropriate torsionmeter. A torsionmeter is placed on the ship's main propulsion shafting to measure the instantaneous torque being applied to the propeller. Knowing the modulus of elasticity of the shaft, its RPM and torsional strain, the shaft horsepower is readily determined. Once shaft horsepower and ship speed are obtained, an algorithm would be used for correcting the effect of other parameters such as ship's displacement, trim, wind direction and speed currents and sea state as well as the ship's dynamics.

- Technology gaps. The principal gaps in technology are:
  - Higher accuracy needed in speed logs
  - Correlation data
- Needed RDT&E. For the fouling diagnosis to be effective, a program to assure repeatability, stability and reliability must be undertaken as a part of this effort.
- Environmental considerations. No environmental problems are anticipated.
- Personnel considerations. The only requirement will be basic indoctrination on the operation and care of the instrumentation as well as interpretation of results obtained during monitoring.

Electrical Measurements of Hull Coating

Essentially, all new ships are being built with an Impressed Current Cathodic Protection (ICCP) system. This system contains the elements for diagnosing the integrity of hull coatings on an overall or average basis. The deviation of the reference cell against set voltage is an indication of the degree of corrosion and/or deterioration of the hull coating.

- State-of-the-art. Work is being performed on a more accurate method for monitoring the condition of the hull. This method is to measure the 'time constant' on the potential.
- Technology gaps. The use of cathodic protection systems and

other electrical parameters as a fouling diagnostic tool is presently just a concept. This general area of correlating the condition of hull coatings with electrical measurements appears to be a promising diagnostic tool requiring a long-term R&D effort.

- Needed RDT&E. Laboratory tests are needed to correlate electrical measurements with condition of coatings. Detailed planning is needed to implement a research and development program for such a diagnostic electrical system.
- Environmental considerations. No adverse impact anticipated.
- Personnel considerations. There should be no need for additional personnel to operate equipment.
- Equipment support. Needs can only be established after the completion of some RDT&E.

Temperature/Flow Differential Monitoring

Fouling on sea chest strainer plates cuts down drastically the intake area and also the amount of seawater that can flow through condensers and other heat exchangers and seawater piping systems. Therefore, measuring the velocity of entering seawater, a small distance downstream from the sea chest, offers a means of developing a seawater piping system fouling diagnostic.

- State-of-the-art. The state-of-the-art, as far as the principle is concerned, is best understood by reviewing the steady state behavior. For this diagnostic approach to be implemented, the following information is required:

- Monitoring of the velocity of the intake, downstream from the sea chest.
- Monitoring of the ship's velocity.
- Effective cross-sectional area at the two given points of the system. (Preferably at the sea chest intake and a measured distance downstream from the sea chest).

A second scheme depends upon the quantity of heat transferred from the engine/pump room into the flowing seawater. It is possible to predict this inside heat transfer coefficient by making measurements of certain selected temperatures. This scheme works as a diagnostic aid as long as there is a temperature gradient between the seawater and engine/pump room.

- Technology gaps. The only gap exists in the development of suitable computation algorithms and the necessary software.
- Needed RDT&E. The necessary RDT&E program includes design of suitable equipment, full scale experimentation, and data interpretation and analysis.
- Environmental considerations. No additional shipboard personnel will be required.
- Equipment support. Only a minor power requirement is anticipated for software electronics.

Propulsion Parameter Correlation

There are a number of engineering plant parameters available on board ship that could be correlated with each other, yielding relationships that could be used as diagnostic aids.

- State-of-the-art. The Navy has begun an effort in the Energy R&D Office at DTNSRDC to use the USS HAROLD E. HOLT (FF-1074) for making correlation studies. One outcome might be to develop an assessment technique for indicating the extent of hull/propeller fouling.
- Technology gaps. The necessary computational algorithms and supporting software would have to be developed to relate the various correlations to fouling.
- Needed RDT&E. It is recommended that present work at DTNSRDC, Code 2705 continue, and that the data base be expanded to include additional parameters, and a program be established to analyze resulting correlations.
- Environmental considerations. No adverse effects are anticipated.
- Personnel considerations. No additional shipboard personnel will be required.
- Equipment support. Only a minor power requirement is anticipated for software electronics.

Measured Distance at Constant RPM

The time required to travel a fixed distance is a measure of the ship's average speed. If this fixed distance is run with the ship maintaining a constant RPM, the time to traverse the distance will increase as fouling increases, as long as ambient conditions are the same.

- State-of-the-art. The constraint on this scheme is limited availability of measured mile ranges convenient to Navy operating areas. It is possible to use satellites for obtaining real-time fixes by those one hundred plus ships so equipped and then compute the distance traveled. Another possibility is the future construction of offshore oil rigs in the Atlantic Ocean. These may serve as convenient distance markers along the coast.
- Technology gaps. The necessary technology exists.
- Needed RDT&E. An evaluation program should be established for use of satellite fixes.
- Environmental considerations. No adverse effects are anticipated.
- Personnel consideration. No additional personnel are required.
- Equipment support. None required.

Noise Measurement

Through the years, fouling has become recognized as a source of ownships' noise which degrades the performance of installed sonar systems. The concept of using this noise as a fouling diagnostic tool may be worth pursuing.

- State-of-the-art. Without being considered a diagnostic tool, noise levels are being used in the submarine community as an indicator of excessive fouling and other noise producing sources.

- Technology gaps. The technological gap which prevents the general use of noise as a fouling diagnostic indicator is the correlation between the level of noise and the level of fouling.
- Needed RDT&E. An RDT&E program would have to pursue two paths. First, identify the data processing equipment and criteria which would best show the fouling produced noise and provide correlation of this noise with observed fouling. Second, correlate information obtained from presently installed own-ships' noise monitors with fouling condition on submarines.
- Environmental considerations. No adverse effects are anticipated.
- Personnel considerations. Personnel considerations will depend on the equipment and mode of operation.
- Equipment support. Equipment support will be dependent on the results of the R&D program.

Time Indexing

The most common use of time as a diagnostic tool is a plot of the power required against time out of dock. Most ships collect little fouling during the first few months out of dock and frequently reach the ten percent extra power level between the ninth and twelfth month. Using these and other results, a time based diagnostic system can be established.

- State-of-the-art. Some locations and conditions are more conducive to fouling than others. Based on this fact, every location could be given a relative rank (say from 1 to 10) where 1 refers to poor conditions for fouling. The proposed time indexing system would assign fouling points to the ship for each day. Depending upon where the ship is and what it is doing, points would be accumulated and when a required number was met the ship would be cleaned. As in most diagnostic systems, the need to clean is not based entirely on the system but on a visual inspection after the diagnostic system exceeds its specifications.

- Technology gaps. All time based systems are examples of statistical analysis of limited data.
- Needed RDT&E. The statistical data base on fouling versus time must be increased.
- Environmental considerations. No effects on the environment are anticipated.
- Personnel considerations. No additional personnel will be required, although a small amount of training may be.

8. INSPECTION METHODS DISCUSSION

Current underwater inspection methods are highly subjective. Quantifiable and repeatable inspection results and associated evaluation criteria are needed. These would permit rational and cost-effective maintenance and repair action decisions, and assist in the development of a complete fouling diagnostic system.

Requirements for top-level underwater hull inspections were reviewed in discussion with the Navy Coastal System Laboratory (NCSL), Panama City, Florida, and with Fleet personnel. In addition, reports from NCSL, MARAD, and from related industries were reviewed. The development of specific software and hardware elements is required.

To conduct comprehensive, accurate inspections of the underwater hulls of ships cost-effectively, a complete inspection "system" must be developed. It must be comprised of properly trained personnel and sufficient, adequate and reliable support equipment.

- State-of-the-art. A state-of-the-art study of underwater inspection methods and equipments was sponsored in fiscal year 1976 by Commander, Naval Sea Systems Command's Ocean Engineering Research and Technology Branch, NAVSEA-0353. The study, conducted by NCSL and entitled "State-of-the-Art Study -- Diver and Remote Vehicle Underwater Inspection", is incorporated into Appendix C as Annex C-II. The study serves as the baseline for further discussions of underwater inspection methods and systems. Data for the report was obtained through contact with cognizant organizations in the United States and foreign countries, including both manufacturers and user activities.
- Diver inspection systems. Many individual equipments have been designed for diver use, but there is no formally designated and totally integrated diver hull inspection system.
- Diver life-support equipment. The most closely managed element

relating to underwater inspections is diver life-support equipment. The Navy diving manual contains extensive guidance and specific regulations pertaining to life-support equipment.

- Inspection-related equipment.
  - Underwater TV systems. Many underwater TV systems are presently available on the commercial market. The U.S. Navy is currently using the Underwater Damage Assessment Television System (UDATS), manufactured by Hydro-Products. Other manufacturers that market underwater TV systems include Cohn, Inc., of San Diego, California; General Aquadyne, Santa Barbara, California; UDI Group, Houston, Texas; Video Sciences International, Woodland Hills, California; Seacor, Inc., San Diego, California; Sub Sea Systems, Inc., Escondido, California; EDO Western Corp., Salt Lake City, Utah; and Rebikoff Institute of Marine Technology, Ft. Lauderdale, Florida.
  - Measurement instruments. Until recent years, diver inspection tools have been very primitive. Some basic tools used to perform certain inspection functions are calipers, gauges, rulers, templates and hammers for determining the level of liquid in a tank. Leak detection, corrosion measurement, and coating evaluation are accomplished by visual inspection only. The Navy has no tools available to assist the divers in these fields.
- Non-Destructive Testing (NDT) Equipment. The Navy has promulgated no list of approved NDT equipment. There are several NDT equipments

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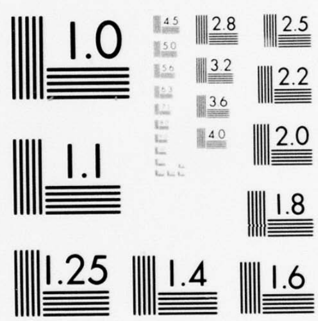

MICROCOPY RESOLUTION TEST CHART
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manufactured by U.S. companies. These devices consist of a metal thickness gauge, an eddy current crack detector, and several ultrasonic gauges. Equipments are available for magnetic particle (MT), ultrasonic (UT), eddy current, dye penetrant (PT), and gamma radiography (RT) testing. Most underwater NDT inspection companies make their own adaptation of dry land equipment based on the type of work involved.

- Boat/working platforms. There is no boat specified for diver use, much less a designated standard boat. The LCM-3, as configured in NAVSEA Drawing No. 145-4777404 Code Ident. 80064 meets the requirement. Only minor modifications would be required on this boat in order to outfit it with the required support equipment.
- Underwater hull location system. There are no formal underwater hull location systems in existence, nor are any equipments designated for such use. There are, however, several crude but effective methods used by the diving community.
- Software. State-of-the-art discussions of diver training are contained in the Software Section of Appendix C.
- Diver training. The hull seaworthiness inspection is a highly specialized skill requiring a relatively large amount of field experience. It may be too much to expect the Navy diver to become a qualified hull integrity inspector. In order to provide the Navy with underwater inspection capability, it is necessary to develop a program for training personnel to conduct the inspections. It would be beneficial to create a special underwater

inspector rating and position description and have such personnel assigned to the group responsible for ship inspection. Otherwise, retention and on-the-job training of personnel will be likely to fall below required standards.

- Inspection standards. In most underwater inspections, the diver is told only to inspect and report the condition found. Standards for evaluation of these observations are not provided. This sometimes results in divers not recognizing defects which exist.
- Inspection reports. A review of report forms being utilized by five Navy diving activities revealed that not all of the items on the suggested form were being inspected.
- Fixed, mobile and remote controlled underwater inspection systems and concepts. Many of these facilities are designed to allow a trained hull inspector to observe the condition of the underwater body close-up in a dry environment.
  - Fixed inspection facility concepts. Specially designed, fixed inspection facilities have the potential of being less labor intensive, hence more cost-effective, than other types of inspection systems, at least for some inspection purposes. One such facility concept would involve the installation of a track system running parallel to the keel line of the ship. On this track a vehicle would operate on which would be mounted the inspection head or array.

    The inspection head would employ equipment operating on one or more of the following principles:

-- TV or photography: Black and white, color, and stereoscopic

-- IR heat sensors

-- Reflectometer

-- Acoustic Holograph (sonoptography)

A facility of this type should be located in water having the best possible visibility. Various Naval stations should be considered to find the ports most suitable for this concept.

- Mobile underwater inspection system. Naval Undersea Center (NUC), San Diego, has been involved in the design and development of four specialized submersibles. These vehicles could have application to the underwater hull inspection portion of the hull husbandry program. Three of the vehicles have a far greater potential range of usage than is required by this program. The added depth capability in this family would increase cost substantially with no equivalent added payoff. The fourth vehicle, Hull Inspection Platform (HIP), is different from the previously mentioned vehicles. It has possibilities as an underwater maintenance tool but extensive engineering changes would be required to make it an effective observation platform.

- Remote controlled inspection systems. Most remote vehicles are designed and constructed to perform specific missions and are of little value as hull inspection tools. The only system known which is used for the inspection of ships' hulls is SCAN, employed by Underwater Maintenance Company, Ltd., of Southampton, England. Due to limitations relating to water current and visibility, SCAN would have limited application in the overall U.S. Navy hull husbandry program.

- Swimmer Propulsion Units. The primary swimmer propulsion unit available in the U.S. is the Rebikoff DR 14 "Pegasus" unit. This unit is more applicable to the inspection of long runs of pipe or cable than to hull inspections. A swimmer propulsion unit is a versatile tool and can be valuable where strong currents are encountered.

- Technology gaps. The basic technology gaps in the area of Navy underwater hull inspection relate largely to the lack of application of existing commerically available equipment.
- Needed RDT&E. What is needed most is test and evaluation of commercially available inspection tools and equipment. The development of underwater hull inspection software such as standardized inspection procedures and reports and diver training is also required.
- Environmental considerations. No effects on the environment are anticipated.
- Personnel considerations. No matter which equipment or procedure is decided upon for the program, more Navy divers and hull inspectors are needed than now exist.

- Equipment support. Equipment support will vary considerably between the modes or methods of inspection to be selected.
- Effectiveness evaluation plans. The development of effectiveness evaluation plans for underwater hull inspection methods cannot be addressed until the methods to be employed have been decided upon.
- Development progress tracking plans. Until specific diagnostic methods are decided upon, only broad program policy guidance is warranted.

SUMMARY

WATERBORNE CLEANING: (APPENDIX D)

1. INTRODUCTION

With today's high fuel costs, merchant ship operators have found it to be economically effective to clean ship's hulls periodically between regular drydockings. This is accomplished while the ships are waterborne.

The main topic of this appendix is waterborne cleaning of ships' hulls, propellers, sonar domes, sea chests and adjacent piping and appendages. This study was undertaken to determine the state-of-the-art, to identify gaps in technology, to develop needed RDT&E, to determine personnel and support facility requirements and to recommend implementation action. The bulk of the study addresses the problem of cleaning fouling with minimum damage to the anti-fouling coating.

2. FINDINGS

- Underwater hull cleaning is a well established practice among tanker and cargo liner operators. The technology of underwater cleaning has developed to the stage that it can now be applied to U. S. Navy ships. In fact, Fleet Commanders are beginning to use the services of established hull cleaning firms to clean hulls prior to ship deployment.
- The best known operation to U. S. ship operators are hand-held brush units and a unit known as SCAMP (Submerged Cleaning and Maintenance

Platform), by Butterworth Systems, Ltd. There are over twelve licensed stations worldwide. More are being established. BRUSHKART, a multi-brush system similar to SCAMP, is also being introduced in cleaning stations worldwide.

- EXXON International studies indicate the following average net fuel cost savings over a 24-month drydock cycle:

At Constant Speed of (knots)	21K DWT Diesel ($K)	50 DWT Steam ($K)	250K DWT Steam ($K)
11	31	127	144
12	33	141	161
13	35	157	188
14	38	185	228

The savings have been achieved with a policy of cleaning the hull each time speed at constant power drops 1/2 knot. This occurs about 12 months out of dock, and then every 3 to 4 months until the next docking.

- Initial trials with USS HAROLD E. HOLT (FF-1074) indicate average annual fuel cost savings at nominal cruising speed to be $86K.

- High pressure (6,000 to 10,000 psi) water jets are currently being used and low pressure (1,500 to 2,000 psi) are under development to clean substructures, platform legs, pipelines, pilings, etc. in the oil industry.

- Cleaning rates with "average" fouling for the most promising systems are:

SCAMP (merchant ship)	17,800 sq. ft./hr.
BRUSHKART	21,000 sq. ft./hr.
Diver Held Rotary Brush	180-2000 sq. ft./hr.
H. P. Water Jet (single)	180-900 sq. ft./hr. (lab result only)
CAVIJET (L. P. Waterjet) single	900 sq. ft./hr. (lab result only)

- A study of SCAMP operations showed virtually no inorganic matter in discharge water and negligible dissolved oxygen demand by organic matter from heavily fouled ships.

3. BRUSH SYSTEMS

Currently, brush systems are the only method by which waterborne ship hull cleaning operations are carried out. Other methods which have been tried experimentally include high pressure water jets and explosive charges.

Brush systems currently in use include a variety of hydraulically or pneumatically driven diver held rotary brush units, BRUSH BOAT, SCAMP, BRUSHKART, and a developmental Japanese automatic underwater cleaning machine.

A major element in the achievement of successful brush cleaning is the characteristics of the brush. Its bristles should be sufficiently stiff to remove the fouling; but they should not roughen and in most cases they should not abrade the antifouling coating.

- Diver-held Rotary Brushes

  Much of the cleaning of Navy ships undertaken to date has been accomplished with diver-held, hydraulically powered rotary brushes.

- BRUSH BOAT - Brush Boat has a long cylindrical brush mounted on a work boat. The brush extends vertically below the surface approximately 8 to 12 feet. It is most effective on the large flat sides of bulk carriers. It is not a viable system for ships having large transverse hull curvature - e.g., most Naval combatants.

- SCAMP - SCAMP appears to be the most widely used of the high production, multiple brush systems. Normal cleaning, which includes the sides to the turn of the bilge, ranges in cost from $5 to $9 per foot of length between perpendiculars for commercial ships. The cost to clean Navy ships is higher because of the increased diver involvement required. The SCAMP machine is 6 feet in diameter and 20 inches deep. It is connected to a control console for remote control or it can be switched to local diver control.

- BRUSHKART - The basic unit is BRUSHKART, a 4.26 foot long by 3.94 foot wide by 1.64 high hydraulically powered vehicle fitted with three brushes, and driving wheels to propel it over the surface being cleaned. The BRUSHKART is operated by a diver lying prone on the unit. He can maintain directional and speed control with a steering wheel and a lever.

- Japanese Brush System - The single brush unit is held to its work by a combination of 3 magnetic wheels. The magnetic wheels are aided by the action of an axial flow pump which draws water through the center of the brush. The discharge water carries removed fouling and paint chips to a filtering and settling tank.

Technology Gaps

There appear to be no significant technology gaps which would inhibit the rapid and effective addition of brushing techniques to the waterborne cleaning of Naval ships. There are, however, developmental areas which require work to ensure that the ultimate system used will be as cost-effective as possible.

Environmental Considerations

A survey of the laws of the United States relating to water pollution control and environmental quality, presently reveal no regulations that would specifically inhibit or prohibit brush cleaning operations. Brush cleaning will not generate the quantity or kind of pollutants associated with general shipyard drydocking operations.

Personnel and Facilities Requirements

Effective waterborne hull cleaning operations are highly dependent upon the employment of skilled diving personnel to carry them out.

If cleaning operations are contracted for, there will be essentially no demand on the Navy to train personnel for the operation, except for a cadre of diver-qualified inspectors to monitor the contractors work. However, should the Navy decide to develop its own facilities and be able to lease or purchase the various systems, operating crews would have to be procured and trained. Contract agreement for procurement of the systems should include the establishment and operation of training facilities.

Summary

The techniques and equipment for waterborne hull cleaning operations by brushing are readily available to the Navy. A well structured program based on either contractor support, the establishment of hull cleaning facilities and operating personnel in key Navy installations or a combination of those two approaches can be initiated at the Navy's will.

4. WATER JET SYSTEMS

Water jet systems have been well established as a means of cleaning land structures for some years. However, their use in cleaning ship's hulls is just beginning.

- High-pressure (5000 to 10,000 psi), diver-held single jet units now are being used for underwater cleaning operations to remove marine growth from substructures, platform legs, pipelines, pilings, etc., in the oil industry.

- A European-developed (by Woma-Apparatebau) ganged jet system, designed to clean ships' sides to the turn of the bilge has been gaining interest recently.
- Experiments have been performed by Hydronautics, Inc. using a relatively low pressure (1500 to 2000 psi) cavitating water jet to clean marine fouling. This system is known as CAVIJET.

Technology Gaps

The basic hardware elements are available to build experimental and perhaps even acceptable prototype water jet systems for the waterborne cleaning of ship hulls. They have the potential for greater flexibility for access into tight areas such as sea chests. It is essential, though, that an RDT&E program be established to evaluate the effects of jet pressure, nozzle size and configuration, jet angle and nozzle standoff, and nozzle advance rate on cleaning efficiency and coating integrity.

Environmental Considerations

Environmental considerations for water jet cleaning systems are essentially the same as for brush systems.

Personnel and Facilities Requirements

Personnel considerations and general equipment support requirements for water jet cleaning systems appear to be essentially the same as for brush systems.

Summary

The hardware elements upon which to base the development of water jet cleaning systems are available. However, in the near future, shipyard operations may be affected by restrictions on pollutants introduced into the water.

SUMMARY

WATERBORNE REPAIR MEASURES: (APPENDIX E)

1. INTRODUCTION

The main objective of these measures is to prolong drydock intervals from the current three year cycle to a projection of as much as five/seven years by means of waterborne repairs. This will result in reduced maintenance costs and increased ship availability.

For major hull repairs (e.g., extensive replacement of hull plating) drydocking or cofferdams are required.

The Navy has made progress in improving certain tasks such as hull cleaning, propeller changes, and sonar dome repair. The adaptation of more advanced technology depends on changes in organization, training, and incentive.

Major development in underwater technology by the offshore industry could be modified for underwater ship repair. Previous underwater work involved emergency repairs. Technology needs to be extended so that repairs of a permanent nature can be effected underwater.

The technology presently available requires only minor adaptation to be used in ship repairs. Major engineering development need only be considered in cases of technological breakthroughs. Repair techniques must show a reduction in cost, increase ship availability, or eliminate the need for drydocks, in order to be considered.

Certain underwater work is limited by available personnel, training and work incentives. Presumably certain repairs could be performed by commercial contractors for technical, economic, or schedule reasons.

2. FINDINGS

Most maintenance and repair work accomplished waterborne has been at less time and expense than comparable drydock work.

- Drydocking is still required for:
  - Stripping and repainting large areas
  - Major repairs to sonar dome rubber
  - Replacing propeller shafts and rudder bearings
  - Major hull structural repairs
- Visibility is critical in completion of underwater repair and inspection. Inspection accounts for 47% of all maintenance dives.
- Partial drydocks, one atmosphere cofferdams and ambient pressure habitats and cofferdams are being used to provide dry atmospheres for underwater production or repair work.
- Current aids for divers to locate their position underwater for hull repair and inspection are crude at best.
- A cadre of personnel qualified in all aspects of underwater inspection and repair does not now exist within the Navy. It has been found more effective by industry to train draftsmen and technicians to dive than to train divers in highly skilled crafts. If the Navy is to carry on a level of underwater repair and maintenance,

training programs and pay incentives are required to develop and retain skilled personnel.

- Underwater components frequently worked on by divers are often welded onto the hull, and are not designed to facilitate underwater maintenance or repair.
- Tools and other equipment, which are adaptations of conventional designs, are available to perform underwater tasks but are in short supply at Navy activities.
- Hydraulic power tools are more effective for underwater use than pneumatic or electric.
- Underwater welds in the dry have been demonstrated in steels similar to MS & HTS but not HY-80. Engineering development of support equipment is needed.
- Wet welding techniques are available for emergency repairs to the hull structure. Permanent repair of critical high strength steel structure must be approached cautiously. Qualification tests in such cases must use a wide range of approaches to seek out latent hydrogen inclusion defects.
- Non-destructive testing (NDT) equipment and techniques for inspection are available. These should be evaluated and standardized to meet Navy requirements.
- Coatings and adhesives capable of being applied in the wet have been demonstrated experimentally. Work is needed to make them fully effective.

3. DISCUSSION

U.S. Navy underwater maintenance is in an immature state. However, expanding the existing concepts will relieve the drydock problem.

Naval shipyards and tenders perform waterborne maintenance and repairs. Capabilities vary from simple tasks using divers to complex tasks involving the use of various equipments.

Design features favoring waterborne maintenance should be incorporated in new ships and integrated into old ones.

Facility Considerations

In choosing a regular waterborne maintenance facility, the port's existing capabilities along with the current fleet operating procedures must be considered.

Diving navigational procedures for hull maintenance presently are not satisfactory when visibility is poor.

Ship underwater maintenance operations should be located in warm, clear water to enhance diver productivity.

Turbidity inhibits the effectiveness of the Underwater Damage Assessment Television System (UDATS) as well as diver inspections.

For diver comfort, a water temperature of at least 60°F is preferred. This also aids in curing epoxy-formulated repair coatings.

Water depth should be at least ten feet greater than keel depth to accommodate Navy ships and provide diver work space underneath the hull.

A tidal current of 1/2 knot may be considered adequate to flush water contaminated by hull cleaning from the area.

Tools

Hydraulic tools are smaller, easier to handle and maintain, are not depth limited, are less noisy and do not create a bubble visibility problem, as do pneumatic tools. Electric tools have the same advantages but do present a potential shock danger and are not readily available. There does seem to be a preference for pneumatic grinders/chippers because closed circuit hydraulic entails manipulation of extra hose.

A comprehensive diver tool package has been developed by the Naval Coastal Systems Laboratory (NCSL) in Panama City, Florida. Costs range from $20,000 to $50,000. The fleet has sixteen kits and two more on order. Hydraulic power tools available in the NCSL kits are: two sizes of impact wrenches, grinder, 80 psi 400 GPM pump, 18 inch chain saw, wire rope cutters, cable cutters, come-a-long, Hurst rescue tool, lift bag, abrasive wheel saw, pneumatic rock drill, and small and large capacity power supplies.

Diving Gear

Diving lockers should be equipped with the best equipment available. Presently, diving gear is in short supply and should be upgraded almost across the board. Such upgrading would be under the cognizance of the NAVSEA Director of Ocean Engineering. Air compressors must be standardized and made more readily available.

Umbilical diving is preferred because it is less bulky and not as time-limited. Scuba is used in areas where umbilicals may get in the way. Dive boats should be large enough to supply divers' needs. A smaller helper boat is a good accessory.

Work Gear

A full assortment of hand and power tools and inspection equipment should be part of the diving locker. Careful records and hull plans should be kept of all inspections and work done on each ship. A stock of common patches and sealing flanges should be kept.

If equipment used weighs over ten pounds in water and the time to do the job is over twenty minutes, then a work platform to do maintenance work should be provided.

- Cofferdams. Bath Iron Works Corporation in Bath, Maine, has developed a unique sonar repair bow dock which is versatile enough to fit many classes of ships.

Based on the Bath Iron Works design, J.J. McMullen has completed a preliminary design for a floating bow dock. It is intended to service present and future ships using SQS-23, 26, 56, sonar domes (except those on aircraft carriers). Plans call for four units, one on each U.S. coast, one at Pearl Harbor, and one for use as needed. These bow docks, able to service sonar dome related problems, would free drydocks for other uses.

The need exists for a small movable cofferdam of standard design and manufacture having air access and suitable for work on the sides and bottom of ships. Work involving welding, cutting, grinding, or painting could be done with this cofferdam instead of a drydock.

The ideal design would allow side fixtures to be installed for sealing against different ships or at various points along the hull. A similar idea traps an air bubble to provide a dry environment. It is held against the hull by mechanical means. This is more suited for use on flat bottoms. In the event of through-hull damage, this hole must be cofferdammed and pressurized from the inside before the bubble can be retained.

The work of providing smaller cofferdams, including patches and sealing flanges, could be streamlined if standard designs and sizes were made available to each facility. NAVSEA abandoned a stern dock concept for servicing propellers, shafts, and rudder because of the difficulty in sealing. Currently under discussion, but not yet funded, is a floating drydock program to service the destroyer fleet starting in FY '80.

- Clear Water Facility. Water having two to three feet visibility is essential to do reliable work underwater. When not available, a simple enclosure could be constructed at the servicing dock. Water could be fresh or filtered from the harbor. Residue removed during the cleaning process could be contained and filtered out without contaminating the harbor.
- Personnel. Ship underwater maintenance and repair will require additional personnel and training.

  The training program should concentrate on shallow water scuba and umbilical diving systems with and without surface communications. Divers should be trained in the use of underwater tools such as those supplied by NCSL.

  Specialists will be needed to perform certain tasks. The Navy has to choose whether to develop its own in-house capabilities or contract with commercial businesses on an as-needed basis.

  It is doubtful that the Navy has enough high quality wet welding work to warrant developing this capability. Most underwater weld repairs could be done using cofferdams. There are several competent wet welding commercial concerns which could be considered when circumstances dictate this method of repair.

  In some cases, such as a diver using UDATS, a specialist on the surface may instruct the diver through a surface-to-diver communication system rather than requiring the specialists to be qualified divers. A central file listing the qualifications and location of all specialists should be maintained for use as the need arises. Records of all work done on a ship must be maintained and kept available for subsequent work in other repair yards.

- Hull Maintenance. Major tasks involving the hull which have not been accomplished waterborne include stripping and painting large areas of the hull, repair of major structural damage to the hull, and repair replacement of large areas of rubber sonar dome windows. Technology and experience may be expected to catch up to these problems very soon.
- Sonar Domes. Recently a section of rubber sonar dome material was completely repaired underwater by using a newly developed B.F. Goodrich patching compound.

  Smaller sonar units may be replaced or repaired underwater with little or no difficulty.
- Sea Chests. Currently much of the in-water work involves sea chests. These openings must be inspected, cleaned, and have valving and piping repaired. When the sea chest is sealed, work can be done in a dry environment.

  Hand scrubbing and waterjets are used to clean through-hull openings.

  Sea suction hull openings are normally covered by an intake grate. Caution should be taken to ensure that all suction pumps are turned off when working around sea chests. To seal off small sea chest openings, wooden or rubber damage control stopper plugs can be used.

Bolt-on flanges should be used to seal off openings, rather than patches. Flanges can be equipped with pipe connections to allow for functions to continue as required. A buoyancy lifting device to handle flanges would be a useful tool to develop.

- Hull Plate and Bilge Keels. Manned Cofferdams may be used to repair moderate structural damage to the hull.

  Bilge keels which are partially torn away from the hull may have the damaged section removed waterborne, but complete repair generally will require either extensive cofferdamming or drydocking.

- Paints and Adhesives. Underwater painting is in an undeveloped state. Available paints are generally expensive, difficult to apply, and often inferior to surface painting materials. Therefore, they should only be used for touch-up or temporary repairs. Surface preparation is the most critical step and fairly difficult to accomplish underwater in any painting effort. Polyester compounds are easier to apply but take longer to cure and are softer and more easily damaged. The effectiveness and lifespan of underwater paints with antifouling additives are inferior compared to air-applied systems.

  The labor (diver) cost for either system is a major cost item. Effective underwater paints and application methods must be developed. Surface preparation must also be developed for effectiveness.

Several systems are presently being developed. At the moment the process of cofferdamming or trimming ship through ballasting to provide a dry atmosphere for conventional application techniques results in the highest quality paint repair.
The same problems exist for underwater adhesives as for paints. Consequently, they should not be relied upon for any kind of critical repair work.

- Appendage Maintenance. This section encompasses all devices which are not an integral part of the hull. Included are propellers, propeller shafting, rudders and corrosion protection systems.
- Propellers. Minor repair and grooming of propellers can be done effectively underwater. There is a need for a small rotary brush specifically designed to clean small sections of propellers. Propellers can be replaced while waterborne using one of several techniques. The best of these are the "Charleston gear" puller or the "Pilgrim nut" method. Both are hydraulic.
The "Pilgrim nut" method for propeller removal should be incorporated in the design of all future ships. Retrofitting existing ships should be considered, perhaps as a part of overhaul procedures. Blades should have a protective covering to protect the working diver from the sharp edge. This would be removed after work on the blades is finished.
Other navies apparently do much more propeller repair underwater, including blade straightening and cutting and welding of damaged sections.

- Shafts. The U.S. Navy has never replaced a propeller shaft waterborne. Other navies do this routinely. Shafts may be removed from inside the ship or externally.

  Struts, fairwaters, and shaft seals require inspection and repair often. Welding of a cracked strut could be done underwater by creating a cofferdam seal instead of drydocking to repair.

  Shaft fairwaters are either bolted or welded in place. Bolted designs are easier to handle underwater and should be a ship design requirement.

  Shaft bearing maintenance and repacking procedures are done from inside the ship. The shaft is sealed at the stern tube by divers.

- Rudders. The repacking of rudder bearings is routinely done waterborne using less manpower and time than in drydock. Flooded rudders are blown out using high pressure air.

  The Navy has the expertise to perform replacement and structural repairs of rudders while waterborne; however, it is generally done in drydock.

  Other navies are reported to do more extensive rudder maintenance, repair, and replacement routinely.

- Corrosion Control. Corrosion control methods include the impressed current system, on new surface ships, and the common zinc anode system. Cofferdamming would make the task of repairing the capastic dielectric shield feasible while waterborne.

Zinc anodes are routinely replaced underwater. Welded zinc anodes should be eliminated from ship design in favor of bolt-on anodes.

- Welding and Cutting. Most of the literature on underwater welding is concerned with welding at great depths.
  There are two kinds of stick-electrode (SMA) process wet welding. There are the "drag" techniques and the new Chicago Bridge and Iron (CBI) multipass technique. CBI weld strengths are equal to in-air welds, although ductilities are typically thirty percent lower.
  At Charleston Naval Shipyard they are attempting to upgrade the "drag" technique to obtain a consistent underwater weld quality. Present quality is adequate for emergency type repairs only. Wet welding may not be suitable for hydrogen-sensitive hull material such as HY-80.
  The toughness required for primary ship structure will be difficult to obtain by wet welding.
- Localized Dry Environment Welding. The HYDROWELD process, developed by Hydro Tech Systems, Inc., appears to overcome the quenching and hydrogen problems in underwater welding of structural steels without requiring a large cofferdam. It remains to be seen whether it can produce quality welds in a quench-and-temper steel such as HY-80.
- Localized Dry Environment Welding. The utilization of HYDROWELD is made difficult if the hull has been penetrated, or if plating must be removed.

- Habitat Welding. Large habitats providing a dry, ambient pressure atmosphere for welders have been developed for pipe-line operations. Welds made in such an atmosphere show physical characteristics equal to those made in air at one atmosphere.
  The HYDROWELD process is basically similar to habitat welding if a large gas enclosure is used.
- Localized Cofferdam Technique. Using localized cofferdams, normal dry welding and cutting may be performed from inside the hull. This low cost technique produces good quality welds subject to the limitations of access to one side only. So far the technique has been used for temporary hull repairs only.
- Welding in Large Cofferdams with Waterline Access. Japanese shipyards use this method in construction of very large tankers: the vessel is built in two sections, each section is launched separately. Then the two sections are floated together and joined with mechanical fixtures. A tunnel-like cofferdam is constructed to span the joint (waterline to waterline). After dewatering the cofferdam, full quality welds can be made to complete the ship.
- Underwater Welding of Nonferrous Materials. No work has been performed on underwater welding of nonferrous materials.
- Metallurgical Aspects of Underwater Welding. Two problems of underwater welding -- hydrogen effects and quenching -- must be considered with respect to their impact on the Navy's requirements.
  - Hydrogen effects. Welding below the waterline, even when performed in a dry habitat, has a great probability of hydrogen

contamination. It is recommended that a detailed study of mechanical properties of underwater welds be conducted by the Naval Research Laboratory to establish test requirements to determine hydrogen contamination.

- Quenching of Welded Steels - The contact of metal with ambient water causes rapid cooling or quenching of the weld, and cracking problems may develop. Welding in a habitat will reduce but not eliminate the problem.

  Laboratory tests have been made to wet weld HY-80 steel using austenitic (E310) electrodes to eliminate the cracking problem. This technique may provide a capability to make temporary repairs in HY-80 steel hulls.

- Specification Activity. MIL-STD-1692(YD) provides general guidance on development and qualification of the underwater welding process with emphasis on wet welding.

  NAVFAC recently initiated several programs in the area of underwater welding and inspection. Welding Institute (U.K.) emphasis is on metallurgical evaluation of the processes, electrode development and arc-behavior. R&D is also being pursued at the following organizations: Massachusetts Institute of Technology (MIT), Government Research Institute (JAPAN), Battelle Memorial Institute (Switzerland), and Mitsubishi Heavy Industries, Ltd. (Japan).

- Underwater Cutting. Current methods for torch-cutting ferrous materials are adequate. However, torch-cutting of non-ferrous metals is undesirably slow for many applications.

- Applications of Present Underwater Welding Technology to Ship Repair. In order to meet a wide variety of potential situations, it would be advisable to have two or three techniques to cover all types of welding repair.

  With respect to weld quality, the following three categories cover most situations: Shipyard Quality weld, Interim weld, and Low Criticality weld.

  The best solution toward eliminating drydocking for underwater repair work would be the development of large cofferdams open to the atmosphere above the waterline.

  Another solution would involve the use of a habitat which mates to the hull and provides a dry atmosphere at ambient pressure.

  An alternative method would be a totally enclosed hard habitat which is entered through an entry-and-exit lock and in which one-atmosphere pressure is maintained.

  Shipyard quality welds might be obtained by these habitat methods in Medium and HTS steels.

  Post-weld painting would be accomplished with Civil Engineering Laboratory (CEL) Epoxy Underwater Paint which could be applied either dry or in-the-wet.

  Interim quality welds could be obtained by the localized cofferdam technique with welding from the inside of the hull. This technique could give good quality joints in Medium and HTS.

Localized cofferdams can be used for replacing sections of hull plating.

Present wet welding techniques are adequate for most applications of low criticality welds.

NDT methods are already state-of-the-art for underwater welding in the commercial field.

- Personnel Considerations in Underwater Welding. All proposed methods involve large amounts of diver work utilizing various skills so that a larger pool of divers than now available would be required.
- Inspection. Few guidelines exist for underwater inspection. A comprehensive document is needed to define effective techniques and acceptable standards.
- Visual. The majority of hull inspections are carried out visually with photographic back-up.

The Underwater Damage Assessment Television System (UDATS) has gained wide acceptance throughout the fleet. A permanent audio-visual record can be made of the inspection, although poor visibility limits its effectiveness.

Color photographs have been useful in documenting paint deterioration, plate corrosion, and fouling conditions.

- Remote Vehicle. Remote inspection systems are not in use within the U.S. Navy, although several are available commercially.
- Non-destructive Testing Underwater. To perform post-weld inspections on welds made underwater, a comprehensive testing capability

for underwater use is required.

- Radiography. Gamma radiography is used extensively in underwater work. This technique gives a permanent record and is insensitive to variations in microstructure. Radiography is available for performing many of the inspection tasks required in underwater hull maintenance. This technique is sometimes ineffective for detection of very tight cracks, so that complementary methods will be needed.
- Ultrasonic Testing (UT). This technique is used for defect examination and thickness measurement in underwater work. Its advantage is detecting tight cracks which may not be found by radiography. A system has recently been developed which permits both the recording of TV camera video and the ultrasonic testing device display.
- Eddy-Current Testing. This technique is used to detect surface-connected cracks and in a composition-sensitive mode to allow identification. It is currently under development in the Navy for periodic surveillance inspection of welds and for detecting dealloying in certain bronze components. It is effective in the detection of hydrogen cracks which are a concern in high strength steels.
- Magnetic Particle Testing (MT). This technique has been used underwater by the offshore industry. However, no details were available concerning the precise procedures followed.

The MT method uses an adhesive magnetic tape which is placed over the area to be inspected. After magnetization, the tape, which now contains indications if cracks are present, is stripped and examined by a special device. The tape may be regarded as a permanent record.

- Navigation Concerns. Poor visibility is the major diver navigational problem. An improved method of underwater position finding is needed.

  Suggested methods which will improve the situation involve visual aids such as underwater grid lines, frame marking and numbering systems. A numbering system is recommended. A sonar navigation system, involving two passive transducers, reference pingers and a diver- or vehicle-held active transducer position indicator would work under all conditions. Accuracies within three inches in 600 feet are within the capability of this type of system.

SHIP UNDERWATER MAINTENANCE, EVALUATION, & REPAIR

(SUMER)

MASTER PLAN

APPENDIX A

SHIP UNDERWATER COATINGS

PREPARED FOR
NAVAL SEA SYSTEMS COMMAND

PREPARED BY:
AUTOMATION INDUSTRIES, INC.
VITRO LABORATORIES DIVISION

APPENDIX "A" - SHIP UNDERWATER COATINGS

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APPENDIX "A" - SHIP UNDERWATER COATINGS

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A.1 INTRODUCTION

The sea is all things to all people. To the naval architect it is a fluid through which ships may move by the expenditure of energy. To the chemist it is a solution containing ions of metallic salts, organic and inorganic compounds. To the electrical engineer it is an electrolyte through which current may pass in accordance with field theory. To the botanist it is the dwelling place of slime molds, algae and phytoplankton. To the zoologist it is the home of the invertebrates and zooplankton. Of course the sea is all of the above things and more.

This study is concerned with coatings which are applied to that portion of a ship's hull which is immersed in seawater, that is, below the normal waterline. The marine coating on the ship's underwater hull is intended to protect it from oxidation, ion exchange and the attachment of marine life. Replacement of coatings used on the underwater hull is normally done while the ship is in drydock.

A.1.1 PROBLEM DESCRIPTION

There are several facets to the problem. The hull structure must be protected from oxidation so that it will retain structural integrity and strength to withstand static and dynamic forces of the sea. Warships are structurally designed with lighter scantlings than commercial ships and, to save weight, have small margins for corrosion allowance. In general, anticorrosive coatings already exist which have an acceptable service life of approximately seven years.

Plant and animal marine life attaches itself to the underwater hull of naval ships and increases the frictional resistance to motion. Shaft horsepower

A.1.1 PROBLEM DESCRIPTION (Cont'd)

and fuel requirements are increased. The very presence of marine growth accelerates the deterioration of the coating system beneath it. Marine growth also constricts the flow of cooling water in sea chests and interferes with the proper operation of sonar installations. The effective service life of present day antifouling coatings is about 18 months to three years.

In addition to problems involving large areas of the hull plating, there are significant problems in localized areas of hull appendages. Rudders are subjected to high velocity, turbulent water which tends to abrade their protective coating. On many ships mechanical abrasion of the hull coating by the anchor chain opens a localized swath of the hull to corrosion and fouling. Sea chests are a special problem. The non-ferrous valve bodies on their inboard end introduce dissimilar metals electrolysis which causes pitting of the steel sea chest. Some sea chests are also subjected to relatively high velocity water flow which tends to abrade their coating.

Another facet of the problem is that underwater bodies of ships are painted in drydocks, and there is a shortage of drydocks. In 1974, Mr. Ginn of NAVSEA testified before the House of Representatives Seapower Subcommittee[1] that:

> "The most urgent problem, as we see it in NAVSEA, is the shortage of drydocks with deep docking capability. This problem is not exclusively a naval shipyard problem but a problem worldwide. Whether we like it or not, our technological advances have obsoleted a large number of drydocks. By the early Eighties, we will be in a drydock critical position on both the east and west coasts."

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[1]The superscripts used throughout the text refer to the number of the source document as listed in the references and bibliography section of this appendix (A.10).

A.1.1 PROBLEM DESCRIPTION (Cont'd)

In the ensuing discussion, Mr. Ginn illustrated the docking requirements of the DD 963 class ship which has an extremely large SQS 53 sonar dome extending deep below the keel. This necessitates building keel blocks twelve feet above the drydock floor! He states that of 37 graving docks which now exist in the naval shipyard complex, only 27 are usable for handling the workload.

An example of these problem areas was seen during the course of a visit to Norfolk Naval Shipyard in August 1976. The USS SPRUANCE (DD 963) was in Drydock #8 at the time. Drydock #4, the only other drydock in the shipyard capable of handling the SPRUANCE, was out of commission for repairs to its pumpwell and will be out of commission for most of 1977 for structural repair work. While examining the ship elevated twelve feet above the drydock floor, it seemed apparent that such height would present complications to any workman, including abrasive blasters and painters performing work on the underwater hull.

Another aspect of the problem concerns the LO-MIX ships which are now being constructed for entry into the fleet. Among the features of logistic management for these ships is an extended interval between periods of depot level maintenance. If long life underwater coatings were available they would enhance the overall maintenance scheme already being planned for these ships.

A.1.1.2 CONSTRAINTS

Selection of an underwater coating for Navy ships' hulls is a systems problem which includes the following aspects:

- availability of raw materials
- established production base of the coating industry in the United States
- procedures for Navy acquisition of the coating material under Armed Services Procurement Regulations (ASPR)
- availability of facilities (drydocks) and necessary industrial production equipment (paint spray guns, abrasive blasting pots, etc.)
- constraints imposed by environmental considerations and matters of occupational safety and health
- necessary procedures for solid waste disposal of debris from painting and spent abrasive fall-out.

While preparing this Appendix it was decided to examine the availability of copper and tin, the two heavy metals most prominently proposed for use as the toxic ingredient in antifouling coatings. The following discussion is based on salient facts contained in Reference 2.

The United States has been the leading copper producing country in the world since 1883. It has a capacity to mine and smelt copper at a rate of 2,000 tons per year. Known reserves of copper in the country are 90 million tons, and undiscovered deposits are estimated to be 320 million tons. The country is self-sufficient in copper, importing 200 tons while experting 189 tons per year. The price of copper on the New York commodity exchange is about 75¢ per pound. In 1967, four countries - Chile, Peru, Zambia, and Zaire - formed the International Council of Copper Exporting Countries (CIPEC) to avoid extreme fluctuations in the price of copper. However, the rank order of copper producing countries is:

A.1.1.2 CONSTRAINTS (Cont'd)

United States, Chile, Canada, USSR, Zambia and Zaire. CIPEC does not hold an important corner on the world market.

"Compared with U. S. demand, domestic mine production of tin is negligible." Demand is about 66,000 tons annually, but U. S. mining capacity is only 300 tons. The only tin smelter in the United States is the Gulf Chemical and Metallurgical Corporation plant at Texas City, Texas. This plant produces about 4,500 tons annually, fed from Bolivian ore. "Measured, indicated, and inferred reserves of tin on lode and placer deposits in the United States total only 42,000 tons, which is insignificant compared with tin reserves of the rest of the world." Tin has been designated as a strategic and critical material. The government stockpile of pig tin was just over 200,000 tons at the end of 1974.

The price of tin is about $4.00 per pound. It is the only metal whose price is controlled by an international agreement between producing and consuming countries. The major producing countries are Malaysia, Indonesia, Thailand and Bolivia. The combined production of these four countries comprised 62% of the world's output in 1974. An International Tin Council (ITC) controls the Tin Research Institute in England and the Tin Research Institute, Inc. in the United States. Their objectives are to develop new uses for tin and improve existing products.

FINDING: The United States is self sufficient in both natural supply and smelting capacity for copper; in the case of tin it is not self sufficient in either.

* * * * *

At this point in the discussion, consideration must be given to the amounts of copper and tin used in antifouling paint formulations. Navy Formula 121/63,

A.1.1.2 CONSTRAINTS (Cont'd)

a cuprous oxide antifouling paint, and Navy Formula 1020A, an organotin antifouling paint, will be used for comparison purposes. As seen from the data in Table I, one gallon of Formula 121/63 contains 12.2 pounds of copper and covers an area of 125 square feet when applied to a dry film thickness of 4 mils. One gallon of Formula 1020A, on the other hand, contains 0.71 pounds of tin and covers an area of 100 square feet when applied to the same thickness. By simple mathematical calculations, one deduces that the weight of copper contained in the volume of Formula 121/63 required to coat a given surface area at a given thickness is about 14 times that of the weight of tin contained in the volume of Formula 1020A required to coat that same surface area at the same thickness.

TABLE I - COMPOSITION DATA ON NAVY FORMULAS 121/63 and 1020A

	Formula 121/63	Formula 1020A
Total Weight Per Gallon (lbs)	20	8.4
Weight of Copper Per Gallon (lbs)	12.2	---
Weight of Tin Per Gallon (lbs)	---	0.71
Percent Copper Per Gallon (by weight)	61	---
Percent Tin Per Gallon (by weight)	---	8.5
Coverage Per Gallon at 4 Mils dry film thickness (FT^2)	125	100

FINDING: Although domestic tin supplies are not as great as those of copper, and although tin costs about 5½ times more per pound than copper, it takes 14 times more copper (by weight) to coat a given surface area than it does tin to coat the same surface area to the same dry film thickness.

A.1.1.2 CONSTRAINTS (Cont'd)

RECOMMENDATION: Ascertain the total annual usage of Formula 121/63 and, from the information given above, estimate the total amount of raw tin that would be required annually to support production of a tin based antifouling paint. Determine whether quantities of tin of this magnitude are readily available at an economic cost.

* * * * *

At the submission of the Navy's FY77 Budget the following key indicators were made public:

Active ship inventory	484 ships
Ship steaming hours	1,153,941 hours
Ship overhauls	105 ships

Implicit in these data are certain parameters germane to this Master Plan. First, it is seen that regular overhauls are planned on about one-fifth of the Fleet, indicating a five year overhaul cycle. This may be one reason for the need for extended life underwater coating. Second, it may be seen that the Fleet will spend about one-fourth of the year steaming, and about three-fourths of the time not under way:

$$\frac{1{,}153{,}941 \text{ hours}}{484 \text{ ships} \times 365 \text{ days} \times 24 \text{ hours}} = \frac{115}{424}$$

FINDING: During FY77 the active Fleet will be comprised of 484 ships. Regular overhauls are planned for 105 of these ships, implying a five year overhaul cycle in gross terms.

FINDING: During FY77 the steaming hours of the active Fleet will be about 1.15 million hours. About three-fourths of its time will be spent not under way, a condition favorable for marine biota to make attachment to the hull.

* * * * *

The established commercial/industrial base for the production of marine coatings imposes a constraint upon the final choice of a product for fleetwide service use. Although research and development efforts ought not be, and are not, fettered by such considerations, logistics planning decisions must reckon with the industrial supply base.

RECOMMENDATION: Ascertain what is the Navy's proportionate share of the national demand for underwater marine coatings. The Navy's position in the market place is germane to the economic feasibility of attracting capital investment to establish a logistic supply line for any product substantially different from that within the capability of the commercial industrial production base.

* * * * *

The workload capacity of coatings engineering manpower in the Naval Ship Engineering Center imposes a constraint upon freedom of action for specifying material. The current modus operandi is that NAVSEC is a participating custodian of various Federal and Military specifications. Inventory management, requirements determination and procurement contracting functions are performed by the General Services Administration Regional Office in Seattle, Washington. The logistics process is largely set in automatic after MIL-specifications and qualified products listings have been established.

FINDING: Coatings engineering personnel resources which may be applied to specification development are limited by a balanced view considering other ship systems. The coating material acquisition process is conducted by logistics personnel outside of the Navy Department. Taken together, this situation

A.1.1.2 CONSTRAINTS (Cont'd)

imposes a real constraint upon the time and attention which may be profitably devoted to underwater coatings and their acquisition.

* * * * *

The availability of facilities and of industrial production equipment represents a constraint upon decision making in the choice of underwater coatings which may be applied to Navy ships. Some years ago, when hot plastic antifouling paint was in vogue, steam jacketed paint pots and heated hose were required to apply the coating properly. Now that airless paint spray guns are being used, equipment to take pressures up to 4,000 psi is necessary. Introduction of toxic antifouling agents in the workplace may bring requirements for personnel protective equipment, such as air fed respirators, and effluent water filters for drydock discharge sumps.

Tools and facilities are discussed in Section A.2.1.7. The facilities and industrial production equipment currently available in the Naval Shipyards to support marine coating processes represent a sizable capital investment. Experience has shown that a change in coating material may require a change in tooling with substantial associated costs. These capital investment costs are a constraint.

FINDING: The cost of facility modification and necessary industrial production equipment must be included when assessing the cost impact of a new coating.

* * * * *

Constraints upon marine coating processes and products imposed by environmental considerations have been real and formidable during the past five years. This subject is discussed more fully in Section A.2.1.4 of this appendix.

* * * * *

A.1.1.2 CONSTRAINTS (Cont'd)

Careful consideration must be given to the eventual disposal of waste products which have been produced by the painting and abrasive blast removal processes. Solid debris remaining from paint application includes paint cans, rollers, brushes, wiping rags and masking material. Liquid debris includes the solvent used for clean up of painting tools, spray guns, hoses and paint mixing pots. Large volumes of solid waste are produced by the abrasive blasting process, typically 300 tons of spent abrasive from the blasting of a submarine hull coated with cuprous oxide based antifoulant.

Present practice with cuprous oxide based antifoulant is to dispose of the aforementioned solid waste in dumping areas belonging to the Shipyard or the local community. However, for painting materials which contain organotin as the toxic agent, NAVSHIPSNOTE 9190 of 28 May 1974 requires that the material be placed in sealed steel drums which may be buried only in a Class I sanitary landfill to prevent toxic leaching into ground water. The foregoing applies to the spent abrasive as well as paint cans, rags and other solid waste debris left over from organotin painting application. Recent experience shows this to be a most important constraint. To date, the only landfills which have been designated as Class I are located in California. Organotin solid waste has been shipped in steel drums from Pearl Harbor to California for burial. At present, one important effort at the DTNSRDC Annapolis laboratory is investigation of detoxification of organotin waste by chemical or thermal methods. One group at the Lab has shown that it is feasible to utilize fluidized bed incineration for the detoxification of all the solid residue resulting from shipyard application of organotin paints. Another group has had promising results with the detoxification of contaminated water wastes. A combination

A.1.1.2 CONSTRAINTS (Cont'd)

of both methods sould eliminate what has been an expensive and disconcerting problem associated with organotin antifouling paints.

FINDING: A major constraint upon the underwater coating process is disposal of solid waste debris known to contain organotin toxicants. This constraint has both economic and environmental aspects.

RECOMMENDATION: Continue the work now under way to develop a method for detoxification of organotin debris which will allow its safe and economic disposal.

* * * * *

A.2 FINDINGS AND RECOMMENDATIONS

A.2.1.1 SUMMARY

The paragraphs contained in this section summarize the findings and recommendations presented in Appendix A. The title preceding each group of findings and recommendations indicates the section of the Appendix in which these topics are discussed.

CONSTRAINTS

FINDING: The United States is self sufficient in both natural supply and smelting capacity for copper; in the case of tin, it is not self sufficient in either.

RECOMMENDATION: Consideration should be given to this factor before making a decision to adopt an antifouling coating which employs a form of tin as its toxic agent.

* * * * *

FINDING: Although domestic tin supplies are not as great as those of copper, and although tin costs about 5-1/2 times more per pound than copper, it takes 14 times more copper (by weight) to coat a given surface area than it does tin to coat the same surface area to the same dry film thickness.

RECOMMENDATION: Ascertain the total annual usage of Formula 121/63 and, from the information given in Table I (pg. A-6), estimate the amount of raw tin that would be required annually to support production of a tin based antifouling paint. Determine whether quantities of tin of this magnitude are readily available at an economic cost.

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A.2.1.1 SUMMARY (Cont'd)

CONSTRAINTS (Cont'd)

FINDING: During FY77 the active fleet will be comprised of 484 ships. Regular overhauls are planned for 105 of these ships, implying a five year overhaul cycle in gross terms.

FINDING: During FY77 the steaming hours of the active fleet will be about 1.15 million hours. About three fourths of its time will be spent not under way, a condition favorable for marine biota to make attachment to the hull.

* * * * *

FINDING: The established commercial/industrial base for the production of marine coatings imposes a constraint upon the final choice of a product for fleetwide service use. Although research and development efforts ought not be, and are not, fettered by such considerations, logistics planning decisions must reckon with the industrial supply base.

RECOMMENDATION: Determine the Navy's proportionate share of the national demand for underwater marine coatings. The Navy's position in the market place is germane to the economic feasibility of attracting capital investment to establish a logistic supply line for any product substantially different from that within the capability of the commercial industrial production base.

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FINDING: Coatings engineering personnel resources which may be applied to specification development are limited by a balanced view considering other ship systems. The coating material acquisition process is conducted by logistics personnel outside of the Navy Department. Taken together, this situation imposes a real constraint upon the time and attention which may be profitably devoted to underwater coatings and their acquisition.

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A.2.1.1 SUMMARY (Cont'd)

CONSTRAINTS (Cont'd)

FINDING: The cost of facility modification and necessary industrial production equipment must be included when assessing the cost impact of a new coating.

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FINDING: A major constraint upon the underwater coating process is disposal of solid waste debris containing organotin toxicant. The constraint has both economic and environmental aspects.

RECOMMENDATION: Continue the work now under way to develop a method for detoxification of organotin debris which will allow its safe and economic disposal.

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ENVIRONMENTAL CONSIDERATIONS

FINDING: Antifouling paint is a marine pesticide within the meaning of the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) 1975. Regulations governing the manufacture, registration, use and disposal of these pesticides are in a considerable state of flux with one important deadline being October 1977. The burden of compliance with existing and forthcoming regulations will impact upon suppliers of marine paint products, but the Navy's concern should be to insure that its logistic supply lines are not disrupted.

FINDING: The Environmental Protection Agency (EPA) Office of Pesticides will become the repository of much data on the chemical composition, toxicity, efficacy and disposal procedures which have been developed by manufacturers.

RECOMMENDATION: From an environmental standpoint it is not yet propitious for the Navy to revise the toxic pesticide agent in its marine antifouling paint. Aftershocks stemming from FIFRA 1975 may disrupt the logistic supply line of the product.

A.2.1.1 SUMMARY (Cont'd)

ENVIRONMENTAL CONSIDERATIONS (Cont'd)

RECOMMENDATION: The Navy should maintain liaison with the EPA Office of Pesticides to acquire extensive data on marine pesticides.

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FINDING: Residue from the industrial processes of application and removal of marine coatings contain pollutants within the meaning of the Federal Water Pollution Control Act. At this time quantified national standards have not yet been fixed for allowable concentrations in drydock effluent water. The EPA is working on the task of developing such standards which will be held applicable to drydocks, both commercial and in naval shipyards.

RECOMMENDATION: Study the results of the water effluent monitoring work which has been in progress for several years. Prepare to make constructive, meaningful comment upon the EPA's drydock effluent standards. Ascertain which of the Navy's drydocks is the cleanest (and the dirtiest) and why.

RECOMMENDATION: Continue support of on-going work for development of the closed-cycle abrasive blasting machine.

RECOMMENDATION: Continue study and implementation of measures for drydock clean-up. Maintain liaison with the Department of Commerce to obtain information on the study being conducted at Avondale Shipyards.

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FINDING: With regard to environmental considerations, hydrocarbon solvents have already heavily impacted the marine coatings systems. The Navy's coatings engineering work force has been drawn away from its normal task of product development into revamping specifications for environmental reasons only.

A.2.1.1 SUMMARY (Cont'd)

ENVIRONMENTAL CONSIDERATIONS (Cont'd)

FINDING: Insufficient time has elapsed to make an accurate assessment of the effects of solvent changes upon the long-term life of underwater coatings in service use. The results of a MIL-specification which had been revised in 1974 for a coating manufactured in 1975 and applied in 1976 may not be seen until 1980.

FINDING: Environmental regulation of hydrocarbon emission from surface coating applications will probably bring additional constraints. Such constraints will be imposed upon the coating industry nationally. U. S. Navy applications are not being singled out for attention.

RECOMMENDATION: Continue to keep informed of EPA hydrocarbon control studies of potential regulations. These must be published in proposed form in the Federal Register.

RECOMMENDATION: Continue to keep abreast of the work being done at Battelle Columbus Laboratories regarding solvent free coatings and their application methods. This is a most valuable alternative for solution of the hydrocarbon emission problem.

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FINDING: From the point of view of hazard to human life, more attention is focused upon particulate matter in the worker's breathing zone (OSHA regulations) than is focused upon particulate matter in the ambient environment. The close-in workman is required to wear an air-fed full face mask and other personnel protective equipment. If the particulate matter contains toxic substances, as compared with mere fugitive dust, the hazard increases by at least an order of magnitude.

A.2.1.1 SUMMARY (Cont'd)

ENVIRONMENTAL CONSIDERATIONS (Cont'd)

RECOMMENDATION: Continue funding support and development of the closed cycle blasting machines.

RECOMMENDATION: Request that the Navy Environmental Support Office again perform physical measurements of the emission of particulate matter from the abrasive blasting process. Do this in other naval shipyards to check repeatability in various locations.

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FINDING: In April 1975, the Chief of Naval Material implemented a Manufacturing Technology Program to promote the timely establishment of improvement of manufacturing processes, techniques or equipment to support current and projected weapon system production requirements. The following projects, related to hull cleaning/protection, have been funded under this program for FY 77.

PROJECT NO.	TITLE
DNS-00355	CO_2 Abrasive Blaster
DNS-00289	Automatic Hull Painter

Other projects related to this subject are slated for funding in subsequent fiscal years.

RECOMMENDATION: Closely monitor these Manufacturing Technology Projects. Make recommendations to the Naval Material Industrial Resources Office (NAVMIRO) concerning projects which should be undertaken in the future.

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A.2.1.1 SUMMARY (Cont'd)

OCCUPATIONAL SAFETY AND HEALTH ACT (OSHA) CONSIDERATIONS

FINDING: The Navy Department has safety and health standards for its personnel which are equal to or better than those promulgated for the private sector in OSHA. Important among these standards are ones pertaining to the application and removal of marine coatings, which do in fact contain toxic and hazardous substances. The costs of necessary personnel protective equipment and facilities must be included when deciding upon adoption of a specific coating.

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RECOMMENDATION: Determine the actions necessary for compliance with the Toxic Substances Control Act which was enacted on 12 October 1976 and Federal Standard 313A which was promulgated on 4 June 1976.

FACILITY/EQUIPMENT REQUIREMENTS

FINDING: The Navy is unable to overhaul the Fleet at the periodicity desired due to a shortage of drydocks among other things. It has been publicly stated that a large "backlog" of ship overhauls now exists[1].

RECOMMENDATION: Consider the construction of more drydocks. Study the possibility of deepening those docks which have been obsoleted due to the lack of deep draft docking capability.

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FINDING: The cost of complying with the prescribed safety precautions associated with the application, removal, and disposal of organotin antifouling paints is substantial.

A.2.1.1 SUMMARY (Cont'd)

FACILITY/EQUIPMENT REQUIREMENTS (Cont'd)

RECOMMENDATION: This cost should be carefully weighed with the benefits derived from employing organotin antifouling paints.

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POLICY

FINDING: The key requirement is for a marine antifouling coating to defeat a wide spectrum of marine phyla and to remain effective for an extended period.

FINDING: Other valuable properties of a long life antifouling coating would be camouflage and reduced sonar reflectance.

RECOMMENDATION: Fund and otherwise continue to support development of organometallic polymer coatings development work at DTNSRDC, Annapolis. This work offers real potential for achieving long life antifouling properties.

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FINDING: The process of selection of a coating for service use is a decision process separate from RDT&E work. Among other things, this decision involves availability of raw materials, manufacturing capability of the commercial production base, industrial engineering for surface preparation and coating application, performance in service use and environmental constraints.

FINDING: Constraints deriving from environmental and from occupational health considerations have increased by several orders of magnitude during the past five years.

FINDING: On-going activity in the marine coating community is prolific and diversified. This activity is of value to Navy coatings programs, and it should be monitored routinely.

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A.2.1.1 SUMMARY (Cont'd)

POLICY (Cont'd)

FINDING: There are currently no prescribed standards which represent the maximum acceptable degrees of fouling on:

a) various ship types

b) specific portions of a ship's hull.

Such standards should be based on a comparison of the costs associated with brushing or replacing a ship's hull coating versus the increased fuel costs and other deleterious effects experienced at different levels of hull fouling.

RECOMMENDATION: Establish such standards for use fleetwide, bearing in mind that fouling on a destroyer tender, for instance, is no where near as critical as fouling on a high speed combatant ship. By the same token, an acceptable level of fouling on a ship's hull proper might be unacceptable on its sonar dome or propeller. The results of tests recently conducted on the U.S.S. HAROLD E. HOLT (FF-1074) to determine the effects of marine fouling on the performance of a Navy ship for selected hull regions could be used as a guide in establishing maximum acceptable degrees of fouling.

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FINDING: The proper application of a marine coating system has perhaps as much effect upon the performance and service life of the system as does the coating formulation itself. For this reason a considerable amount of effort should be devoted to assuring proper application of marine coatings in Naval shipyards.

RECOMMENDATION: Close liaison should be maintained between the Navy's R&D community which is striving to develop new and better marine coating systems and the Shop 71 painters who are tasked with applying these systems at the Naval shipyards. Liaison can be accomplished via the existing NAVSEA Steering Group

POLICY (Cont'd)

for Surface Preparation and Painting Equipment and Methods Standardization Subcommittee.

* * * * *

WHAT CAN BE DONE NOW?

RECOMMENDATION: Complete the work, already in process, of re-formulating the cuprous oxide based antifouling paint, Navy Formulas 121 and 129, so as to obtain compliance with hydrocarbon emission limitations.

RECOMMENDATION: Resume performance appraisal or evaluation of underwater coatings on active Fleet ships in the "as docked" condition.

RECOMMENDATION: Update and re-publish the chapter of the NAVSHIPS Technical Manual on "Preservation of Ships in Service".

RECOMMENDATION: Obtain from the Environmental Protection Agency a copy of the Development Document for proposed effluent limitations to navigable waters from drydocking and ship repair point sources.

NEEDED RDT&E

FINDING: The development work upon organometallic polymers (OMP's) which has been under way for several years is comprehensive, orderly and holds real promise for producing an antifouling coating with a service life span of at least five years. This work is nearing fruition.

NEEDED RDT&E (Cont'd)

RECOMMENDATION: Fully support the RDT&E work for formulating and evaluating OMP antifouling coatings at DTNSRDC, Annapolis.

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RECOMMENDATION: As an RDT&E task, examine the possibility of developing submarine coatings which provide camouflage and reduced sonar reflectance.

RECOMMENDATION: As an RDT&E task, examine the possibility of developing underwater coatings to reduce structureborne radiated noise.

EFFECTIVENESS EVALUATION PLANS

FINDING: The U. S. Coast Guard has a stated goal of five-year service life for marine antifouling coatings to use on its ships and buoys. It is sponsoring long-term panel tests to evaluate premium coating material.

RECOMMENDATION: As a minimum, maintain continuing liaison with and monitor the results of panel tests being conducted by the Coast Guard/Battelle Laboratories at Daytona Beach, Florida. Consider joint funding sponsorship of this valuable on-going work.

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FINDING: Use of the Docking Report, Form NAVSHIPS 9070, as a mechanism for recording the condition of the underbottom coating "as docked" was abandoned about 1961. At present the Docking Report records only the coatings which were applied during the drydock period.

RECOMMENDATION: Draw up a form sheet in the NAVSHIPS 9070 series entitled Underwater Coating Evaluation. Include among the reportable items of information most (all) of those elements which were contained in the Form 223 of

EFFECTIVENESS EVALUATION PLANS (Cont'd)

vintage 1955. Utilize only observers with coating expertise to fill out this form, rather than perfunctory remarks from casual observers.

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FINDING: At such future time when certain recommendations of this Master Plan have received approval, there will be a need for a single manager to assure that they are implemented.

RECOMMENDATION: A Program Manager in the Naval Sea Systems Command should be designated as the executive agent to implement the recommendations of this Master Plan. His responsibilities should include the following:

- drafting a policy directive to be promulgated by OPNAV
- identifying fund resources in the budget necessary to foster these recommendations
- ascertaining and tracking the progress of the program

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FINDING: Naval Shipboard underwater coating systems presently in use are being specified by "cookbook" type procurement specifications, that is, the exact ingredients and the quantity of each are spelled out. This procedure intrinsically fixes the service life of the coating, assuming that proper application techniques are followed.

FINDING: The anticorrosive coating specification, MIL-P-23236, is a working precedent for the use of performance type specifications. The government does not specify the ingredients of the coating material, which is formulated proprietarily by the manufacturer.

A.2.1.1 SUMMARY (Cont'd)

EFFECTIVENESS EVALUATION PLANS (Cont'd)

FINDING: During the course of this study, no instance was observed wherein extended antifouling properties of a coating could be demonstrated and proven by means of laboratory tests or extrapolation of short term tests. Advertising and proprietary claims are being made that a five-year life antifouling coating already exists based on abbreviated test results.

* * * * *

NAVY FORMULA 150 SERIES/FORMULA 121/63

FINDING: The Navy's current hull coating system is one of the best marine coating systems available today.

RECOMMENDATION: Continue to use the Formula 150/Formula 121/63 coating system until a system is developed which offers a major improvement (e.g. doubles the service life) over the existing system.

SEAMASTER SYSTEM

FINDING: Though the Seamaster System appears to offer excellent anticorrosive/antifouling protection for extended period of time, the System has not yet been fully tested.

RECOMMENDATION: Establish contact with the JOTUN Marine Coatings Company and the commercial shipping lines using the Seamaster System to monitor the results of the service tests now in progress.

GOODRICH "NO-FOUL"

FINDING: Goodrich "No-Foul" has exhibited superlative anticorrosive/antifouling properties in panel tests[6] and in actual service use.

A.2.1.1 SUMMARY (Cont'd)

GOODRICH "NO-FOUL" (Cont'd)

RECOMMENDATION: Continue to monitor the performance of "No-Foul" on Navy ships. Ascertain the effectiveness of the product on hull appendages (e.g. rudders, struts, roll stabilization fins, etc.) which are subjected to high velocity water flow, and also in seachests.

RECOMMENDATION: Ascertain whether the disposal requirements applicable to wastes containing organotin paints[11] should be applied to wastes generated during the application and removal of Goodrich "No-Foul", since the product contains tributyltin oxide.

A.2.1.2 STATE-OF-THE-ART

As discussed earlier, an underwater marine coating system is comprised of two major components - an anticorrosive coating to protect structures from oxidation, and an antifouling coating to prevent the adherence and growth of marine organisms. For many years the marine coatings industry has placed primary emphasis on developing coatings which would provide corrosive protection. The need is critical since unprotected metallic structures submerged in seawater will eventually deteriorate and fail. The consequences of attachment of marine organisms to underwater metal structures are not as critical. The most deleterious effect of marine fouling occurs after a long period of time when attached biota pentrate the anticorrosive coating, resulting in decreased resistance to the oxidizing action of the seawater[3]. In today's era of markedly increased fuel prices and diminishing petroleum supplies, hull fouling presents additional problems. Tests conducted by the Navy in FY74 indicate a potential reduction in fleet fuel costs of $40,000,000 annually if hulls can be kept free of marine fouling[4]. Commercial shipping lines stand to save even more by maintaining "barnacle-free" bottoms due to their fleets' extremely high percentage of hours under way. Thus, it is now evident that substantial fuel and associated monetary savings may be realized by the employment of effective antifouling coatings.

Because industry has focused its attention on solving the more serious corrosion problem, anticorrosive coatings technology is far more advanced than present day technology in antifouling coatings. The gap is clearly evidenced by the difference in the effective service lives of anticorrosive and antifouling coatings. Anticorrosive coatings have proven effective for periods as long as

A.2.1.2 STATE-OF-THE-ART (Cont'd)

seven years, while the maximum service life of antifouling coatings is about three years. Thus it is currently the antifouling component of a ship's underwater coating system that delimits the coating refurbishment/replacement cycle.

Numerous types of anticorrosive and antifouling coatings are available on today's market. These may be classified by their generic type, the most common of which include: Alkyds, Vinyls, Chlorinated Rubbers, Acrylics, Epoxies, Polyurethane, Water Base, and Solvent Base[5]. These may be further subdivided by the basic material used in the coating formulation; for example, the generic type "Epoxy" includes coatings which are formulated from epoxyamines, epoxy polyamides, epoxy coaltars, or epoxyesters. Thus, there are many types of coating formulations and an even greater number of possible coating system formulations, since a system may employ different generic types of anticorrosive and antifouling coatings.

Since the number of marine coating systems is so large and since comparative studies have already been conducted on many of these systems, this report will address only the following five marine coating systems:

1) Navy Formula 150 (series)/Formula 121/63
2) Seamaster System (Jotun Baltimore Copper Paint Co.)
3) Self Polishing Copolymer (International Paint Co.)
4) "No-Foul" - (Goodrich Corporation)
5) Navy Formula 1020A

In a long-term test of underwater marine coating systems, conducted by Battelle Laboratories and the U.S. Coast Guard from 1969 to 1975, a system employing Navy

A.2.1.2 STATE-OF-THE-ART (Cont'd)

Formula 121/63 and another comprised of Goodrich "No Foul" received the two highest ratings of the 18 systems evaluated[6]. During the test, each system was subjected to 51 months of static immersion and 10 months of dynamic immersion on a rotating drum apparatus. Both the Navy System and the Goodrich Product provided outstanding corrosion and fouling protection. Seamaster and Self Polishing Copolymer are relatively new marine coating systems which have demonstrated excellent performance in their application on foreign navy and commercial vessels. Paragraphs A.3 through A.7 of this appendix describe the general properties, performance characteristics, and pro's and con's of each of these five systems. Table II summarizes the technical data available on each system.

A.2.1.2 STATE-OF-THE-ART (Cont'd)

TABLE II - TECHNICAL DATA ON HULL COATING SYSTEMS

	NAVY FORMULAS 150 Series A/C 121/63 A/F	SEAMASTER SYSTEM	SELF POLISHING COPOLYMER	"NO-FOUL"	NAVY FORMULA 1020A
MANUFACTURER OR MIL-SPEC NUMBER	MIL-P-24441 A/C MIL-P-15931 A/F	JOTUN MARINE COATINGS CO.	INTERNATIONAL PAINT CO.	GOODRICH CO.	EXPERIMENTAL SPECIFICATION ONLY
GENERIC TYPE	EPOXY POLYAMIDE A/C VINYL A/F	CHLORINATED RUBBER	PROPRIETARY INFORMATION	ELASTOMERIC SHEET	VINYL A/F
RECOMMENDED USES	BOTTOM RUDDER SEA CHEST STRUTS	BOTTOM RUDDER SEA CHEST STRUTS	BOTTOM	BOTTOM RUDDER SEA CHEST STRUTS SONAR DOMES	BOTTOM RUDDER SEA CHEST STRUTS
SURFACE PREPARATION	ABRASIVE BLAST TO NEAR WHITE STATE	ABRASIVE BLAST TO MINIMUM OF SA 2½	APPLY OVER A/C COATING	ABRASIVE BLAST TO WHITE STATE	APPLY OVER A/C COATING
RECOMMENDED METHOD OF APPLICATION	AIRLESS SPRAY	AIRLESS SPRAY	AIRLESS SPRAY	PROPRIETARY ADHESIVE	ROLLER OR BRUSH
NUMBER OF COATS	3 A/C 2 A/F	5 A/C 4 A/F	3 A/F	1 LAYER	2 A/F
TOTAL DRY FILM THICKNESS (MILS)	12	29	11 (A/F ONLY)	80	4 (A/F ONLY)
COLOR	A/F GREEN GRAY DARK GRAY A/F RED	A/F RED	A/F RED GRAY WHITE	BLACK	A/F BLACK
TOXICANT	CUPROUS OXIDE	CUPROUS OXIDE	TRIBUTYLTIN OXIDE	TRIBUTYLTIN OXIDE	TRIBUTYLTIN OXIDE AND FLUORIDE
EFFECTIVE SERVICE LIFE (MONTHS)	18 - 36	48 - 60 (WITH 3 TO 4 REACTIVATIONS)	24+	120	36
SUBSTRATES	STEEL	STEEL	STEEL ALUMINUM	STEEL ALUMINUM WOOD	STEEL ALUMINUM
SOURCES OF INFORMATION (REFERENCE NOS.)	22, 32	33, 34, 35	37	6, 38	4, 11, 40

A.2.1.3 GAPS IN TECHNOLOGY

Before addressing specific deficiencies in today's marine coatings technology, it might be appropriate to discuss the general progress of the marine coatings industry over the last half century. In his paper entitled "The Role of the Biologist in Antifouling Research"[7], Dennis Crisp summarizes the progress as follows:

> "Within the paint industry itself, the past forty years has witnessed a considerable improvement in the reliable life of cuprous oxide paints, but, apart from the recent introduction of some new organometallic based paints, very little progress indeed has been made on novel or imaginative lines. Much of the research has been repetitious on account of the numerous firms all engaged in parallel investigations on traditional materials and the progress achieved appears to me to have been unduly costly.
>
> For the sake of future developments, it is worth considering the causes of this disappointing rate of progress. I would suggest three factors stand out. First, it has to be recognized that copper oxide as a basis for antifouling paint is difficult to improve upon. It has a high toxicity over a wide spectrum of groups of animals and plants. It is not difficult to prepare and formulate nor unduly expensive. Hence the tendency in the industry has quite understandably been to seek improvement in cuprous oxide paints rather than to search for other materials and methods. Secondly, the performance of ships' paints is notoriously variable even under raft conditions, let alone on ships. Sales cannot, therefore, be expected to rise sharply following the introduction of a marginally improved product; indeed,

by the time a new product has proven itself, competitors will already be marketing compositions skillfully slipped through the net of the patent laws. In this situation, investment in exploratory science is difficult to justify against investment in sales and advertising. Thirdly, the structure of the industry mitigates against scientific progress. It consists of a number of relatively small competing units usually working on small profit margins; none of them are capable of sustaining a major research effort such as the problem needs. Nor is it possible to imagine their being able to coordinate their efforts within the existing commercial system."

Mr. Crisp's remarks may be easily substantiated by merely examining the history of the antifouling coatings used by the U.S. Navy. From 1908 to 1926, the Navy used a shellac type bottom paint with occasional slight modifications[8]. In 1926, a coal tar resin formulation was adopted and used until World War II. In the period from World War II to the Korean War, the Navy utilized a hot plastic coating system, and later, a cold plastic system, both of which employed cuprous oxide biocides[3]. After the Korean War a wash primer pretreatment was developed which assured good adhesion of vinyl paints to steel hulls. Hence, the Navy developed, tested and adopted Formulas 121 and 129, vinyl antifouling coatings with cuprous oxide toxicant. These formulas, which were slightly modified in 1963 are still the Navy's most effective and widely used antifouling hull coatings. Thus, one can see that cuprous oxide has been the Navy's principal antifouling agent over the past three decades. Not until recent years have the Navy and industry begun experimenting with paints employing other types of marine biocides.

A.2.1.3 GAPS IN TECHNOLOGY (Cont'd)

In regard to specific gaps in today's marine coating technology, one must consider not only the deficiencies existent in coating formulations themselves, but gaps in other related areas as well. The degree of understanding of fouling organisms, for example, and the state-of-the-art in coating application and removal methods are two important factors which directly affect the advancement rate of marine coating technology. The following paragraphs discuss the apparent gaps in each of these areas.

Marine Biology

From an overview of the reference material utilized in this study, it is evident that the kill or repellent mechanism of present day antifouling toxicants is not fully understood. It is unclear why some toxicants are highly effective against certain species of marine organisms but have only a limited effect upon others. Cuprous oxide, for example, offers a high degree of resistance to barnacles, but a much lower degree of resistance to tubeworms. Organotin, on the other hand, has proven highly effective against tubeworms, but less effective against barnacles. Though DTNSRDC/A has developed OMP resins which have exhibited long-term resistance to a wide spectrum of marine biota, these resins have not yet been formulated into marine paints.

Thus, there exists a need for a hull coating with a broad base toxin which would repel all types of marine biota for extended periods of time. A further understanding of the biology of marine fouling organisms might well be the key to developing such a coating.

Coating Formulation

The technology gap most apparent in current marine coating formulations is the difference in the service lives of anticorrosive and antifouling paints.

A.2.1.3 GAPS IN TECHNOLOGY (Cont'd)

As mentioned earlier, current anticorrosive paint formulations are effective for periods of up to seven years, whereas antifouling coatings require replacement at two to three year intervals. This is perhaps the most critical technology gap, for it governs the periodicity at which a ship's hull coating system must be refurbished or replaced.

Resistance to the scouring action of high velocity seawater is another property which is lacking in current day marine coating formulations. No coating has proven 100% effective in long-term protection of a ship's rudders, struts, roll stabilization fins, etc. The high velocity water flow and resultant cavitation to which these hull appendages are subjected during underway periods tends to scour away the coating, leaving the appendages vulnerable to fouling and corrosion.

Still another technological gap related to marine coating formulations is the lack of a suitable accelerated testing device to determine the efficacy of newly developed marine coatings. Though a rotating cylinder apparatus has been used to simulate shipboard service conditions, the effect of varying pH, salinity, temperature, oxygen content and turbulence of seawater on the aging and leeching rates of coatings has not been studied in relation to the test apparatus[10].

The aforementioned technology gaps apply to marine coating formulations in general. Deficiencies in specific coating systems are related in Sections A.3 through A.7 of this appendix.

Application and Removal Processes

As emphasized by Francis LaQue in his book on Marine Corrosion[5], "the key to the effective protection of steel by marine coatings is proper

A.2.1.3 GAPS IN TECHNOLOGY (Cont'd)

application. The best formulated coating can be completely ineffective if poorly applied. Conversely, a relatively poor coating can be made quite satisfactory through proper and careful application." LaQue suggests that blast cleaning is the best method for preparing steel for the application of a marine coating since it cleans the steel of all contaminants and provides a new fresh metal surface over which to apply the paint. At this time, as discussed in Section A.2.1.4 of this appendix, environmental regulations are constraining abrasive blast operations. Although closed cycle blasting machines have been introduced at naval shipyards, the machines have radius-of-curvature limitations which preclude their use on the entire hull of a ship. The closed cycle bottom blaster at Norfolk Naval Shipyard, for example, is capable of blasting only flat bottomed vessels. Similarly, the closed cycle side blaster at Norfolk is useful only on relatively flat, vertical surfaces. It cannot be used on the curved hull of a submarine, for example.

A second technology gap related to abrasive blast operations lies in the area of disposal of spent abrasive containing organotin. NAVSHIPS NOTICE 9190 of 28 May 74[11] requires that all wastes generated from the blasting of organometallic paints be placed in steel drums, sealed and buried in Class I sanitary landfills or approved dumping sites. Such disposal requirements are extremely costly due to the large volume of wastes generated during abrasive blast operations. As an illustration, an estimated three hundred 55-gallon drums would be required for the disposal of the solid wastes generated from the blast cleaning and painting of one SSBN[12].

Work is currently under way at DTNSRDC/A to develop a means of chemical detoxification of organometallic abrasive blast wastes, thereby eliminating the need for this costly waste disposal procedure [13].

A.2.1.3 GAPS IN TECHNOLOGY (Cont'd)

Environmental regulations make limitations on spray painting operations. As previously mentioned, about 50% of the volume of paint used to coat a hull consists of volatile solvents which escape into the atmosphere during spray operations. Present day technology has not yet produced a "solvent free" paint suitable for use on ships' hulls, but R&D efforts to develop such a product are currently under way at Battelle Columbus Laboratories in Columbus, Ohio[14].

The following is another technology gap related to the application of hull coatings. There is currently no means of coating the surfaces of a ship's hull which are masked by keel and side blocks while the vessel is in drydock. Since there are three positions in which a vessel may be docked on its blocks, each keel and side block area is exposed to paint application during two out of three drydock periods. Thus, if a vessel is drydocked at four-year intervals, individual block areas are coated only once every eight years. This condition is unsatisfactory since eight years exceeds the effective service lives of today's anticorrosive and antifouling hull coatings. It is reported that one Russian drydock is fitted with hydraulically driven blocks which permit dismantling under load[15].

The adoption of Double Universal Fitted Side Blocks by naval shipyards provides labor and material cost savings, however, it complicates the problem of corrosion prevention in the block areas of the hull. Under this system, which is described in Reference 15, half of the side block areas on a ship's hull will be painted only once in three dockings while the other half will be painted twice in three dockings. Half of the side block areas will thus be coated only once every twelve years if a ship drydocked on Double Universal Fitted Blocks at four-year intervals.

A.2.1.4 ENVIRONMENTAL CONSIDERATIONS

The use of underwater coatings interfaces with the environment in many ways. Antifoulant toxins are marine pesticides deliberately displayed on the underwater hull to repel or kill zooplankton and phytoplankton which attempt to live upon the hull. These toxins are designed to leach continuously from the coating surface into the marine environment. The normal industrial process for hull surface preparation, sandblasting or abrasive blasting, has already been the subject of an Environmental Impact Statement[16]. The volatile hydrocarbon solvents, which comprise about one-half the volume of coatings, are atmospheric pollutants. Marine coatings that have been removed from the hull and cleaned up from the drydock floor become a solid waste disposal problem. Residue on the drydock floor, which is not cleaned up or which is washed into the drydock sump, may be discharged into navigable waters. Each of the above mentioned environmental interfaces will be discussed in more detail.

At the outset of this discussion it must be emphasized that it is already U. S. Navy policy to "... actively participate in a program to protect and enhance the quality of the environment"[17]. This includes many measures which have already been taken in compliance with pollution abatement laws and regulations. The intent of the discussion is to show where current regulations delimit choice of alternatives.

One group of regulations which is germane are those stemming from the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA), Public Law 92-516 of October 21, 1972 as amended by Public Law 94-140 of November 28, 1975[42]. The regulations for enforcement of FIFRA are found in Title 40, Code of Federal Regulations, Part 162 (40 CFR 162) and they were published in the Federal Register on 3 July 1975. It is clear that these regulations apply to antifoulant

A.2.1.4 ENVIRONMENTAL CONSIDERATIONS (Cont'd)

paint mixtures, since among the definitions of pesticides is given:

> "... invertebrate animal poisons and repellants includes all substances or mixtures of substances intended for preventing the establishment of, destroying, repelling, or mitigating invertebrate animals, including:
> (a) Antifouling agents intended for use on boat and ship bottoms, pier and dock pilings, and similar submerged structures to prevent attachment or damage and destruction by marine invertebrates."

Also included in the definition of pesticides are: fungicides, herbicides, algaecides, nematicides and slimicides.

Based upon the provisions of FIFRA as enacted in 1972, the Environmental Protection Agency drew up a document in May 1974 setting forth its strategy for controlling the adverse effects of pesticides[18]. It anticipated a need to classify and register more than 40,000 pesticides. When FIFRA was amended by the Congress in 1975, EPA found it necessary to alter its strategy paper. A copy of the preliminary draft of the EPA's new strategy dated July 1976[19] covering the outyears 1976 - 1981 was acquired. This was reviewed to obtain an insight into regulatory actions which might be forthcoming in the future.

Although the regulations and the EPA strategy are better discussed in their complete, original form, salient features are delineated below.

(a) There are two levels of control, Supply Control and Use Control. Supply Control is effected by prohibiting the sale of a pesticide until the manufacturer has applied for and obtained EPA registration of the product. Registration may be given for General Use or Restricted Use. Use Control of a registered product is effected by requiring that Restricted

A.2.1.4 ENVIRONMENTAL CONSIDERATIONS (Cont'd)

Use products may be applied only by a certified applicator. Labeling requirements are the primary use control strategy for General Use products.

(b) The deadline for obtaining EPA registration of pesticides is October 1977, two years after the enactment of Public Law 94-140.

(c) Pesticide products which have previously been registered under the 1972 FIFRA must be re-registered by October 1977 with new and additional data requirements. Registration is valid for an ensuing five year period and is not automatically renewed.

(d) Provision is made for the issuance of experimental use permits for RDT&E purposes.

(e) The applicant for registering a pesticide must provide detailed data concerning the product, including: complete chemical composition; manufacturing process and purity; efficacy in use; acute toxicity data regarding human hazard from oral, dermal, inhalation and ocular exposure; hazard to non-target organisms; safe methods for disposal of the pesticide and its container.

FINDING: Antifouling paint is a marine pesticide within the meaning of FIFRA 1975. Regulations governing the manufacture, registration, use and disposal of these pesticides are in a considerable state of flux with one important deadline being October 1977. The burden of compliance with existing and forthcoming regulations will impact upon suppliers of marine paint products, but the Navy's concern should be to insure that its logistic supply lines are not disrupted.

FINDING: The EPA Office of Pesticides will become the repository of much data on the chemical composition, toxicity, efficacy and disposal procedures which have been developed by manufacturers.

A.2.1.4 ENVIRONMENTAL CONSIDERATIONS (Cont'd)

RECOMMENDATION: From an environmental standpoint it is not yet propitious for the Navy to revise the toxic pesticide agent in its marine antifouling paint. Aftershocks stemming from FIFRA 1975 may disrupt the logistic supply line of the product.

RECOMMENDATION: The Navy should maintain liaison with the EPA Office of Pesticides to acquire extensive data on marine pesticides.

* * * * *

Another interface between ship underwater coating systems and the environment concerns regulations deriving from the Federal Water Pollution Control Act (FWPCA). At the heart of the matter is the National Pollutant Discharge Elimination System (NPDES) established by Section 402 of the FWPCA and for which procedural regulations are given in the Code of Federal Regulations, Title 40, Part 125. These regulations require that permits be obtained from the Environmental Protection Agency (EPA) for each end-of-the-pipe discharge into navigable waters. The permits also require the discharger to monitor his effluent and report results to the EPA.

Marine coatings are removed and fresh coatings applied while ships are in drydock. Fall out debris from both of these processes drops to the floor of the drydock or to any other horizontal surfaces that exist, such as altars, stairwells and the top of drydock blocks. Shipyards do the best possible job of cleaning up this debris, but the probability exists that some portion reaches the drydock drainage system and is pumped into navigable waters. For the past several years, effluent samples from drydock outfalls have been monitored and subjected to chemical analysis for turbidity, pH, and heavy metal content.

A.2.1.4 ENVIRONMENTAL CONSIDERATIONS (Cont'd)

The strategy of the NPDES is to fix upon nationally enforceble, quantified standards for the pollutant content of effluent discharges from each individual industry. Such effluent standards have already been promulgated by the EPA for many industries; for example, iron and steel manufacturing, paint formulating, and electroplating. There are many more industries and manufacturing processes for which such standards have been set forth. The complete list may be found in Title 40, Code of Federal Regulations, Subchapter N, Effluent Guidelines and Standards. The standard for drydocking operations has not yet been promulgated, but the EPA is working on it. It was learned that Hittman Associates, Columbia, Maryland, is working under contract to the EPA to draw up such a standard, with a target date of about 1 November 1976.

The naval shipyards have applied for and have been issued NPDES permits applicable to the liquid discharges from each drydock sump. These permits are being issued by the appropriate Regional Office of the EPA. Two selected pages of EPA Permit #VA0005215, issued to Norfolk Naval Shipyard by the Region III Office[20], are inserted in this narrative text to illustrate major elements of a water effluent permit.

Effluent characteristics which EPA finds to be significant are turbidity, heavy metal compounds, oily waste and hydrogen ion content. Numerical limitations on the allowable concentration of these elements have not yet been set. The heavy metals listed are those which might be expected to be found in paint residue.

Special attention is invited especially to Notes 5 and 6 which make a clear call for housekeeping activity and first rate clean-up of the drydock

Effluent Limitations and Monitoring Requirements Discharge

During the period beginning October 1, 1975 and lasting through expiration date of permit the permittee is authorized to discharge from outfall(s) serial number(s) 003, 004, 005, 006 (drainage pump discharges)

Such discharges shall be limited and monitored by the permittee as specified below:

Effluent Charac.	Discharge Limitations				Monitoring Req.	
	kg/day(lbs/day)		Other Units(Specify)			
	Daily Avg	Daily Max	Daily Avg	Daily Max	Measurement Frequency	Sample Type
Flow-m3/Day(MGQ)	N/A	N/A	N/A	N/A	1/month	estimated
Suspended Solids	N/A	N/A	N/A	N/A	1/month	composite*
Settleable Solids	N/A	N/A	N/A	N/A	1/month	composite
Lead	N/A	N/A	N/A	N/A	1/month	composite
Chromium (Total)	N/A	N/A	N/A	N/A	1/month	composite
Arsenic	N/A	N/A	N/A	N/A	1/month	composite
Copper	N/A	N/A	N/A	N/A	1/month	composite
Zinc	N/A	N/A	N/A	N/A	1/month	composite
Mercury	N/A	N/A	N/A	N/A	1/month	composite
Tin	N/A	N/A	N/A	N/A	1/month	composite
Cadmium	N/A	N/A	N/A	N/A	1/month	composite
Oil and Grease	N/A	N/A	N/A	N/A	1/month	grab

Monthly certification signed by a responsible Navy official of compliance with "Water Pollution Control Plan."

The pH shall not be less than 6.0 standard units nor greater than 8.5 standard units and shall be monitored 1/month utilizing a grab sample.

There shall be no discharge of floating solids or visible foam in other than trace amounts.

Samples taken in compliance with the monitoring requirements specified above shall be taken at the following location(s): Outfalls 003, 004, 005 and 006 at the point of discharge (if not submerged or from the pumps).

*This discharge must meet conditions A and D for Graving Docks listed under other requirements.

Other Requirements:

A. Graving Docks

1. All sanitary wastes must be collected to the maximum extent practicable and discharged to a municipal waste treatment system, or to a sanitary treatment system which will meet secondary treatment requirements by July 1, 1977.

2. Shipboard cooling water, process water and sanitary wastes will be directed so as to minimize contact with spent abrasive. This includes water required for ship repair and testing. The testing of external ship structures with pressure hoses shall be permitted.

3. Water leakage from the graving dock gate must be intercepted in order to prevent it from flowing across the drydock floor. This water will then be sent directly to the drydock sump without making contact with the drydock floor other than with installed drains.

* 4. Hydrostatic relief water and other water entering through or over the sides must be intercepted and conveyed directly to the drydock sump. No contact other than with installed drains is permitted with the drydock floor.

5. The permittee shall install the proper equipment in all water conveying systems which will minimize the discharge settleable solids and floating materials including oil and grease and paint. The direct discharge of floating materials, settleable solids (including abrasives), paint, and oil and grease to the drydock sump and hence to the receiving water is prohibited unless provisions are implemented to remove the above pollutants from the sump prior to discharge. This condition does not apply to settleable solids brought into the dock from the waterway as a result of flooding.

6. The permittee shall prevent the discharge of spent abrasive by removing abrasive from the floor of the dock as soon as practicable. The drydock floor must be cleaned of spent abrasive to the equivalent of a scraped or broomed clean condition prior to flooding. Proper safeguards are to be implemented in order to minimize contact of water other than rain water with the spent abrasive.

7. Requirements 2, 3, and 4 will not apply if requirement 5 has been met. This exception applies only when the spent abrasive has been removed from the floor of the drydock and no additional spent abrasive will be discharged to the drydock floor prior to flooding.

8. The permittee shall comply with the above requirements (2 through 7) within 18 months after the effective date of this permit.

* This condition shall not apply to hydrostatic relief water which enters through the floor of the graving dock.

floor. In this connection, it was observed that the Commerce Business Daily of 10 August 1976 carried a notice that the U. S. Department of Commerce had awarded a contract to Avondale Shipyards to study cleaning of drydocks prior to flooding. The Naval Sea Systems Command promulgated an advisory to all naval shipyards on this very subject in its letter ser 302-073 of 16 June 1975.

FINDING: Residue from the industrial processes of application and removal of marine coatings contain pollutants within the meaning of the Federal Water Pollution Control Act. At this time, quantified national standards have not been fixed for allowable concentrations in drydock effluent water. The EPA is working on the task of developing such standards which will be held applicable to drydocks, both commercial and in naval shipyards.

RECOMMENDATION: Study the results of the water effluent monitoring work which has been in progress for several years. Prepare to make constructive, meaningful comment upon the EPA's drydock effluent standards. Ascertain which of the Navy's drydocks is the cleanest (and the dirtiest) and why.

RECOMMENDATION: Continue support of on-going work for development of the closed-cycle abrasive blasting machine.

RECOMMENDATION: Continue study and implementation of measures for drydock clean-up. Maintain liaison with the Department of Commerce to obtain information on the study being conducted at Avondale Shipyards.

* * * * *

Another interface between marine coatings and the environment arises from federal regulations related to the Clean Air Act. Of the declared air pollutants, two are of special interest - hydrocarbons and suspended particulate matter.

A.2.1.4 ENVIRONMENTAL CONSIDERATIONS (Cont'd)

The environmental objection to the concentration of gaseous hydrocarbons is that they react with nitrogen oxides under the influence of sunlight and produce a wide variety of photochemical oxidants which have an adverse effect upon human health and plant growth. The objection is not upon the direct effects of the hydrocarbons themselves. The volatile portion of most common surface coatings is approximately 50% of the coating applied, therefore one-half of the material used goes onto a ship's hull and the remainder goes into the atmosphere. Reference 21 lists hydrocarbon emission factors and states that generally 1,120 pounds of hydrocarbons are emitted for each ton of paint applied. In the case of zinc chromate primer, the emission is 1,320 pounds per ton.

Rule 66 of the Los Angeles Air Pollution Control District sets a weight-per-day limitation upon discharges of hydrocarbons to the atmosphere[43]. This rule makes a distinction between photochemically reactive and non-photochemically reactive organic solvents. Emission of only 40 pounds per day of the former is permitted, but as much as 3,000 pounds per day of the latter is allowed. A number of other jurisdictions have adopted Rule 66 as a regulatory model in their area.

About 1972 the Navy began a program of reformulating its paint and coatings specifications to delete photochemically reactive solvents and substitute other so-called non-photochemically reactive solvents. This in itself is an example of the impact of environmental regulations upon the marine coating technology. In 1976, after four years of extensive technical efforts, the program to modify some 85 specifications is nearing completion. It has never been represented that this technical effort brought about an improvement in service use, quality,

A.2.1.4 ENVIRONMENTAL CONSIDERATIONS (Cont'd)

or life of the coating. The effort was undertaken for the sole purpose of compliance with an environmental regulation. It is an example of Navy leadership in maintaining and improving the quality of the environment.

NAVSHIPS NOTICE 9190 dated 31 January 1974[22] is an example of the Navy's logistic system reacting to environmental constraints. The NOTICE concerns vinyl primer, formula 119, which is specified in MIL-P-15929 C. This procurement specification contains two paint formulas, a Composition G for general use and a Composition L for limited use in areas where non-photochemically reactive hydrocarbon solvents must be used. One purpose of the NOTICE is to promote draw down of inventory stocks of Composition G while the procurement pipeline is being filled with Composition L.

An address was given by Mr. James A. McCarthy, Stationary Source Control Technology Office of the Environmental Protection Agency, to the Symposium of the Washington Paint Technical Group on 12 April 1976. The theme of this symposium was the interaction/conflict of coatings technology and government regulations. Mr. McCarthy indicated that the so-called non-photochemically reactive hydrocarbons do in fact react to produce atmospheric smog. The reaction takes place only with a delay in time; e.g. hydrocarbons released in Omaha may react over Cleveland.

A portion of this address is quoted below to provide a glimpse into future prospects in this area:

> "EPA is mounting a major new effort aimed at developing and promulgating performance standards for significant emitters of hydrocarbons. Standards have been promulgated for petroleum storage and gasoline marketing. Also under way are studies of the drycleaning and degreasing industries. Most

A.2.1.4 ENVIRONMENTAL CONSIDERATIONS (Cont'd)

importantly for you, we are also in the process of initiating a major study of the industrial surface coatings industry including paper and paperboard coating. Engineering studies will narrow the scope to a manageable number of significant emitters and then detailed engineering, economic and environmental impact studies will be performed to develop new source performance standards. By late 1976 or in 1977 these new source performance standards may be proposed.

"In the near future, I also strongly suspect some States will begin to move toward emphasizing new coatings technology and away from add-on controls and the use of exempt solvents. I expect exempt solvents to be allowed as an interim control option, but only if no other reasonable option is available. It seems clear that in the long run "exempt" solvents as the sole control method will be phased down significantly.

"In summary, hydrocarbon control regulations over the past few years have been turbulent and confusing. I wish I could tell you that this situation is resolved. I cannot. The future will also be turbulent, but I firmly believe that we are in the process of developing more rational approaches to solving the many problems, and you can soon begin to plan your future thinking in terms of pollution control with more confidence. EPA will work with you, through our Regional Offices, and our engineering and enforcement activities. We are always available to help you solve your problems in as equitable a manner as possible."

One alternative coating system is a solvent free liquid resin being worked on at Battelle Columbus Laboratories. Epoxy-polyamide and polyurethane coatings

A.2.1.4 ENVIRONMENTAL CONSIDERATIONS (Cont'd)

have been successfully applied to steel test plates. The application process includes airless paint spray guns, application pressures up to 3,000 psi, and heating the material to about 150°F. The hydrocarbon emission problem is eliminated. Other advantages which this experimental system offers are decreased fire hazard and lower cost[14].

FINDING: With regard to environmental considerations, hydrocarbon solvents have already heavily impacted the marine coatings systems. The Navy's coatings engineering work force has been drawn away from its normal task of product development into revamping specifications for environmental reasons only.

FINDING: Insufficient time has elapsed to make an accurate assessment of the effects of solvent changes upon the long-term life of underwater coatings in service use. The results of a MIL-specification which had been revised in 1974 for a coating manufactured in 1975 and applied in 1976 may not be seen until 1980.

FINDING: Environmental regulation of hydrocarbon emission from surface coating applications will probably bring additional constraints. Such constraints will be imposed upon the coating industry nationally. U. S. Navy applications are not being singled out for attention.

RECOMMENDATION: Continue to keep informed of EPA hydrocarbon control studies of potential regulations. These must be published in proposed form in the Federal Register.

RECOMMENDATION: Continue to keep abreast of the work being done at Battelle Columbus Laboratories regarding solvent free coatings and their application methods. This is a most valuable alternative for solution of the hydrocarbon emission problem.

A.2.1.4 ENVIRONMENTAL CONSIDERATIONS (Cont'd)

* * * * *

The emission of suspended particulate matter to the atmosphere is another environmental consideration which interfaces with marine underwater coatings. The principal area of concern is the abrasive blasting process which does such an excellent job of preparing the metal surface to receive and bond with the primer coat. The spray painting process itself may produce very fine particles atomized by the spray gun which are fine enough to remain suspended in the atmosphere.

Attention to the abrasive blasting process gave rise to the preparation of an Environmental Impact Statement on this subject by the Naval Sea Systems Command[16]. An important part of the examination of this process was physical measurements made by the Navy Environmental Support Office during abrasive blasting operations at Long Beach Naval Shipyard in September 1975. The results of these measurements were: (a) the mass emission factor for the process is about one pound per ton, that is one pound of particulate matter becomes airborne for each 2,000 pounds of abrasive passing through the blast nozzle and impinging upon the ship's hull; (b) only about 15% of this airborne particulate matter is of small diamter so as to remain airborne beyond the shipyard property line, and about 85% falls out inside the shipyard; (c) elemental analysis of the suspended particulates showed that the principal constituents were silicon, calcium, iron and copper.

During a visit to Norfolk Naval Shipyard, it was learned that the Virginia State Air Pollution Control Board had recently expressed a desire to observe abrasive blasting operations. This is mentioned as evidence of environmental interest[23]. Virginia Air Pollution Control Regulations mention "sandblasting"

A.2.1.4 ENVIRONMENTAL CONSIDERATIONS (Cont'd)

in its Rule 4.04.02, Control of Fugitive Dust, wherein it calls for reasonable precautions to be used including:

> "Installation and use of hoods, fans, and fabric filters to enclose and vent the handling of dusty materials. Adequate containment methods shall be employed during sandblasting or other similar operations."

The above is a very general statement and lacks quantified emission limitations. Most commonly allowed particulate emission rates are specified in regulations as being some portion of the weight of raw material entering into the process. For example, in the case of general manufacturing operations the maximum allowable particulate emission rate (E) is given by the formula:

$$E = 4.10 \times P^{2/3}$$

where (P) is the process weight rate. In Virginia, if the process weight rate (P) were one ton per hour, the maximum allowable emission rate (E) would be 4.10 pounds per hour.

A multitude of devices and novel processes are being evaluated which control and minimize emission of particulate matter to the atmosphere. Very heavy capital investment has been made in commercial and naval shipyards to erect large, closed buildings inside of which abrasive blasting and painting processes may be carried on. Typically, these buildings are fitted with ventilation fans to provide high rates of air change plus baghouses to filter exhaust air. The buildings are sized large enough to handle structural sections of ships and, more germane to this study, large hull appendages such as rudders, sonar domes, and amphibious craft.

Closed cycle abrasive blasting machines have been built which may be placed on the drydock floor. These feature a box-like head which is held against the

A.2.1.4 ENVIRONMENTAL CONSIDERATIONS (Cont'd)

hull of the ship and inside of which steel shot abrasive is flung against the hull surface. A pilot model of a bottom blaster for use on the generally horizontal plating of ships' flat bottoms is in use at Norfolk Naval Shipyard[23]. Pilot models of closed-cycle side blasters are being used, one at Norfolk Naval Shipyard and one at Long Beach Naval Shipyard. As the name implies, they are designed to clean the generally vertical surfaces of ships' side plating.

Two schools of thought exist relating to abrasive blasting techniques, i.e. wet blasting versus dry blasting. Adherents of wet blasting maintain that an 80% reduction in fugitive dust may be obtained when a small amount of water, say two or three gallons per minute, is sprayed to surround the abrasive blast cone. Advocates of dry blasting maintain that they obtain a better metal surface for bonding with the primer coat and point out that a chemical inhibitor must be introduced in water spray to prevent rust. This inhibitor, diammonium phosphate plus sodium nitrite, becomes part of the water effluent from the drydock.

FINDING: The abrasive blasting process is an integral part of hull coating technology because the superior metal surface condition it produces enhances the performance, bond and life of the coating itself. The process results in release of suspended particulates to the atmosphere, and has therefore been a subject of environmental concern.

FINDING: From the point of view of hazard to human life, more attention is focused upon particulate matter in the worker's breathing zone (OSHA considerations) than is focused upon particulate matter in the ambient environment. The close-in workman is required to wear an air fed full face mask and other personnel protective equipment. If the particulate matter contains toxic

A.2.1.4 ENVIRONMENTAL CONSIDERATIONS (Cont'd)

substances, as compared with mere fugitive dust, the hazard increases by at least an order of magnitude.

RECOMMENDATION: Continue funding support and development of the closed cycle blasting machines.

RECOMMENDATION: Request that the Navy Environmental Support Office again perform physical measurements of the emission of particulate matter from the abrasive blasting process. Do this in other naval shipyards to check repeatability in various locations.

* * * * *

In April 1975, the Chief of Naval Material implemented a Manufacturing Technology Program to promote the timely establishment or improvement of manufacturing processes, techniques or equipment to support current and projected weapon system production requirements. The following projects, related to the application of hull coating systems, have been funded under this program for FY 77.

PROJECT NO.	TITLE
DNS-00355	CO_2 Abrasive Blaster
DNS-00289	Automatic Hull Painter

Other projects related to this subject are slated for funding in subsequent fiscal years.[44]

RECOMMENDATION: Closely monitor these Manufacturing Technology Projects. Make recommendations to the Naval Material Industrial Resources Office (NAVMIRO) concerning projects which should be undertaken in the future.

A.2.1.5 OSHA CONSIDERATIONS

Closely related to environmental considerations, which have been previously discussed, are matters of occupational safety and health for employees who are working at or in the vicinity of surface preparation and coating application. A body of Federal Regulations has been promulgated on this subject, deriving from the Occupational Safety and Health Act of 1970 (OSHA). Executive Order 11807 requires that safety programs for Federal employees shall be "consistent" with standards prescribed by OSHA.

The code of Federal Regulations, Title 29, Part 1915 is entitled "Safety and Health Regulations for Ship Repairing". It is illustrative to quote from selected portions of these regulations and to begin this discussion with the definition of hazardous material as given in part 1915.2(s):

> (s) For purposes of § 1915.57 the term "hazardous material" means a material which has one or more of the following characteristics: (1) Has a flash point below 140° F, closed cup, or is subject to spontaneous heating; (2) has a threshold limit value below 550 p.p.m. in the case of a gas or vapor, below 500 mg./m.^{3} for fumes, and below 225 m.p.p.c.f. in case of a dust; (3) has a single dose oral LD_{30} below 500 mg./kg.; (4) is subject to polymerization with the release of large amounts of energy; (5) is a strong oxidizing or reducing agent; (6) causes first degree burns to skin in short time exposure, or is systemically toxic by skin contact; or (7) in the course of normal operations, may produce dusts, gases, fumes, vapors, mists, or smokes which have one or more of the above characteristics.

The regulations then require that certain data describing the hazardous materials must be compiled and that employees must be instructed regarding the nature of the hazards. This is set forth in part 1915.57:

> §1915.57 Health and sanitation.
>
> (a) No chemical product, such as a solvent or preservative; no structural material, such as cadmium or zinc coated steel, or plastic material; and no process material, such as welding filler metal; which is a hazardous material within the meaning of §1916.2(s) shall be used until the employer has ascertained the potential fire, toxic, or reactivity hazards which are

A.2.1.5 OSHA CONSIDERATIONS (Cont'd)

likely to be encountered in the handling, application, or utilization of such a material.

(b) In order to ascertain the hazards, as required by paragraph (a) of this section, the employer shall obtain the following items of information which are applicable to a specific product or material to be used:

(1) The name, address, and telephone number of the source of the information specified in this paragraph, preferably those of the manufacturer of the product or material.

(2) The trade name and synonyms for a mixture of chemicals, a basic structural material, or for a process material; and the chemical name and synonyms, chemical family, and formula for a single chemical.

(3) Chemical names of hazardous ingredients, including, but not limited to, those in mixtures, such as those in: (i) Paints, preservatives, and solvents; (ii) alloys, metallic coatings, filler metals and their coatings or core fluxes; and (iii) other liquids, solids, or gases (e.g., abrasive materials).

(4) An indication of the percentage, by weight or volume, which each ingredient of a mixture bears to the whole mixture, and of the threshold limit value of each ingredient, in appropriate units.

(5) Physical data about a single chemical or a mixture of chemicals, including boiling point in degress Fahrenheit; vapor pressure, in millimeters of mercury; vapor density of gas or vapor (air=1); solubility in water, in percent by weight; specific gravity of material (water=1); percentage volatile, by volume, at 70° F; evaporation rate for liquids (either butyl acetate or ether may be taken as 1); and appearance and odor.

(6) Fire and explosion hazard data about a single chemical or a mixture of chemicals, including flash point, in degrees Fahrenheit; flammable limits, in percent by volume in air; suitable extinguishing media or agents; special fire fighting procedures; and unusual fire and explosion hazard information.

(7) Health hazard data, including threshold limit value, in appropriate units, for a single hazardous chemical or for the individual hazardous ingredients of a mixture, as appropriate, effects of overexposure; and emergency and first aid procedures.

(8) Reactivity data, including stability, incompatibility, hazardous decomposition products, and hazardous polymerization.

(9) Procedures to be followed and precautions to be taken in cleaning up and disposing of materials leaked or spilled.

A.2.1.5 OSHA CONSIDERATIONS (Cont'd)

(10) Special protection information, including use of personal protective equipment, such as respirators, eye protection, and protective clothing, and of ventilation, such as local exhaust, general, special, or other types.

(11) Special precautionary information about handling and storing.

(12) Any other general precautionary information.

(c) The pertinent information required by paragraph (b) of this section shall be recorded either on U. S. Department of Labor Form LSB 00S-4, Material Safety Data Sheet, or on an essentially similar form which has been approved by the Occupational Safety and Health Administration. Copies of Form LSB 00S-4 may be obtained at any of the following regional offices of the Occupational Safety and Health Administration:

(Locations of offices deliberately omitted.)

A completed form shall be preserved and available for inspection for a period of 3 months from the date of the completion of the job.

(d) The employer shall instruct employees who will be exposed to the hazardous materials as to the nature of the hazards and the means of avoiding them.

(e) The employer shall provide all necessary controls, and the employees shall be protected by suitable personal protective equipment against the hazards identified under paragraph (a) of this section and those hazards for which specific precautions are required in Subparts B, C, and D of this part.

(f) The employer shall provide adequate washing facilities for employees engaged in the application of paints or coatings or in other operations where contaminants can, by ingestion or absorption, be detrimental to the health of the employees. The employer shall encourage good personal hygiene practices by informing the employees of the need for removing surface contaminants by thorough washing of hands and face prior to eating or smoking.

(g) The employer shall not permit eating or smoking in areas undergoing surface preparation or preservation.

(h) The employer shall not permit employees to work in the immediate vicinity of uncovered garbage and shall ensure that employees working beneath or on the outboard side of a vessel are not subject to contamination by drainage or waste from overboard discharges.

A.2.1.5 OSHA CONSIDERATIONS (Cont'd)

In Part 1910.1000 of the regulations, entitled "Air Contaminants", there are listed the allowable threshold values of many hazardous substances. Most of them are not germane to this discussion, however, selected ones found in underwater coating systems are listed in the Table III below:

TABLE III - THRESHOLD LIMIT VALUES

SUBSTANCE	8-Hour Allowable Exposure Level	
	ppm	mg/m^3
FORMULA 150 - 156		
Titanium Dioxide	---	15
Butyl Alcohol	100	300
FORMULA 121 and 129		
Methyl Normal Butyl Ketone	100	410
Copper Mists	---	1.0
Xylene	100	435
FORMULA 1020A		
Tin, organic compounds	---	0.1
Titanium Dioxide	---	15
Ethylene Glycol Monoethyl Ether Acetate	25	120
Normal Butyl Acetate	150	710

The foregoing data is indicative of the relative toxicity of the substances mentioned, but it would be necessary to make physical measurements on the job to ascertain concentrations being experienced. Where two or more hazardous substances are in the worker's breathing zone simultaneously, the allowable exposure level is reduced by a weighting formula which is given in the regulations. The industrial hygienist of the shipyard has expertise in recognizing and measuring concentrations of these substances.

A.2.1.5 OSHA CONSIDERATIONS (Cont'd)

The same considerations which prompted the OSHA regulations moved the Navy Department to adopt (normally first) safety regulations for protection of its personnel. Reference 11 is one of these, prescribing specific work procedures for application and removal of organotin antifouling paint. In a more general sense, OPNAVINST 5100.17 states as a policy that safety and health standards shall be adopted which are consistent with OSHA standards.

FINDING: The Navy Department has safety and health standards for its personnel which are equal to or better than those promulgated for the private sector in OSHA. Important among these standards are ones pertaining to the application and removal of marine coatings, which do in fact contain toxic and hazardous substances. The costs of necessary personnel protective equipment and facilities must be included when deciding upon adoption of a specific coating.

The Toxic Substances Control Act was enacted on 12 October 1976 and this has a relationship to occupational health considerations and the painting process. The following excerpt from the House Committee Report[24] explains how the committee perceives the situation:

> Each Federal agency, under Section 19 of the Occupational Safety and Health Act, is required to maintain a comprehensive occupational safety and health program. This Committee previously reviewed and reported on the progress of the Federal agencies in meeting this requirement, with particular emphasis on safety.[80] During its investigation, the Manpower and Housing Subcommittee visited a number

[80]House Committee on Government Operations, Safety in the Federal Workplace. H. Rept. No. 784, 94th Cong., 2d Sess. (1976).

of Federal installations throughout the country to examine safety and health programs at that level. At several installations, safety and health officials complained that chemical products they received from the Federal supply system were often not identified or labeled with anything other than a Federal stock number. They contrasted this lack of information with data that they received from suppliers whom they dealt with on a local purchase basis. In general, installations contended that if they themselves purchased the product, they demanded a data sheet or other identification of hazardous materials. When products were issued to them, on the other hand, they too often had no way of knowing whether workers were being exposed to hazardous chemicals.

This situation, which was widespread, occurred despite a clear Federal requirement that all Federal purchasers obtain material safety data sheets for hazardous industrial chemicals. In 1971, the General Services Administration issued Federal Standard 313, entitled "Symbols for Packages and Containers for Hazardous Industrial Chemicals and Materials." That standard provided symbols for labeling interior and intermediate packages containing hazardous materials and required the submission of material safety data sheets on hazardous substances by contractors of manufacturers. The standard specifies that Government agencies shall make reference to it in all purchase orders, contracts, and other purchase documents to assure that the requirements are made clear to the contractors. Shortly after the promulgation of the standard, the Department of Transportation objected that this new system conflicted with the DOT labeling system required for outside containers. Subsequently, that portion of the standard was dropped, but the requirement for material safety data sheets remained in effect.

Like other employers, the Federal Government is required to alert workers when they are exposed to concentrations of hazardous chemicals above safe levels. The Federal Government is not doing this, despite directions from the President that it should be an exemplary employer in the field of occupational safety and health. To determine whether toxic substances are present in the workplace, the employer must know the ingredients of the products purchased for use in that workplace. Despite the existence of F.S. 313 and the buying power of the U. S. Government, the Federal employer does not know when materials contain hazardous substances. The investigating subcommittee's hearings disclosed that F.S. 313 had not been enforced by the two largest buyers in the Federal Government--the General Services Administration and the Department of Defense. GSA testified that it "sort of ignored the matter," and that it had data sheets for only about 100 products it purchased despite the fact that Federal Standard 313 covered thousands of these products.[81] The Defense Department's record was also unimpressive. It explained that the Standard "fell by the wayside and was never fully implemented in the DOD procurement procedures."[82]

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[81] Hearings, p. 150.
[82] Hearings, p. 119.

A.2.1.5 OSHA CONSIDERATIONS (Cont'd)

The investigating subcommittee was particularly concerned with the failure of Departments to implement this standard. The standard is clear in its requirements, and makes the obligation to furnish these sheets quite explicit. Read by itself, the standard would convince an outside party that the Federal Government had foreseen the problem of hazardous chemicals in its workplaces and moved effectively to deal with it. Only after discovering the actual situation in various U. S. Government field installations did the subcommittee learn that there was widespread ignorance of procurement regulations protecting Federal employees and almost no enforcement of these regulations.

Following the hearings, the subcommittee made further inquiries into the progress made in securing material safety data sheets with items purchased. Federal Standard 313 was reissued as F.S. 313A on June 4, 1976, with the former labeling indicia removed. The Defense Department is now working to include the Federal Standard as part of the Armed Services Procurement Regulations, and the Safety and Health Policy Committee in the Office of the Secretary of Defense is devising methods for pooling and disseminating information received from data sheets supplied pursuant to the standard. The Defense Department estimated that safety data sheets are required for at least 10,000 items currently used in DOD installations. The Department further reported that it now has on hand about 2,000 up-to-date data sheets. The magnitude of the task is clear.

The General Services Administration has not moved as forcefully as the Defense Department. Three months after the hearing, GSA had acquired only 122 additional data sheets, the majority of them as a result of a specific request from an installation. At that time, they were unable to estimate the number of items now under contract for which data sheets are required under the standard. GSA has given instructions to its quality control officers throughout the country to review all contracts to determine compliance with F.S. 313A. Each of these officers is to report the number of data sheets on hand and the number required under present regulations. It appears that these steps by GSA management should produce results; but we are disturbed by the faltering start and the suggestion of bureaucratic inertia.

The experience of the Federal Government illustrates the problem of enforcing a requirement to disclose contents through pressure on the employer. Federal employers are required to obtain data sheets under the Federal standard, and private employers in the shipbuilding industry face similar requirements under the Longshoremen and Harbor Workers' Act.[83] From the testimony at the hearings, it appears that neither of these systems has produced satisfactory results. Some private employers visited by the subcommittee contended that they refused to purchase chemical products if data sheets were not supplied, and they had on hand

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[83] 29 C.F.R. § 1915.57 (1974).

A.2.1.5 OSHA CONSIDERATIONS (Cont'd)

a much larger number of data sheets than any Federal installation. Their success in compelling disclosure may not necessarily prove that every employer can do so; despite its sizable purchasing power, the Federal Government seemed sometimes unwilling and sometimes unable to obtain full disclosure of ingredients. Even with newly announced willingness to enforce Federal Standard 313A, there will still be technical problems with performance oriented specifications, since a product can often satisfy the intended use even though ingredients are substituted. When the ingredients substituted are not toxic, this does not pose a problem as far as workplace hazards are concerned; but should the manufacturer introduce a toxic ingredient in one of his batches, some change in the data sheet will be required.

Federal authorities seem convinced that they will be able to enforce this standard; but the difficulties encountered by the Federal employer show the problems that might be expected by a small employer less able to enforce demands for information. For this reason, the Committee strongly favors the enactment of legislation which would put the burden of disclosure upon the original manufacturer or formulator.

Under the Occupational Safety and Health Act, the Department of Labor has the power to set occupational health and safety standards and to inspect and fine employers who do not adhere to them. The Department can address the chemical identification issue by requiring that all employers have material safety data sheets on each toxic substance in their plants, as is now required for the shipbuilding industry. However, the Federal Government is not empowered to confront this problem at its source by regulating chemicals directly; that is, by requiring chemical manufacturers to label products and disclose toxic ingredients, or by requiring the testing of chemical products for toxic properties. There are no Federal statues (except the fuel additive provisions of the Clean Air Act) that authorize control of toxic chemicals because of their health and environmental effects. Current Federal laws do not provide the means for discovering the adverse effects on health and environment of new chemical substances before they are marketed.

Congress has been considering legislation to close this regulatory gap for five years.[84] Successive Toxic Substances Control Acts have given the Environmental Protection Agency the authority to require labeling, specify the manner of disposing of chemical substances, or even ban substances entirely. Under the most recent legislation, chemical manufacturers would be required to test potentially toxic products and to submit reports and maintain records on any adverse health and environmental effects.

[84] In two previous Congresses both Houses passed a toxic bill, but the Conference Committees were unable to resolve the differences in the bills and report out a compromise bill. At the time this report was completed, the House-Senate conference has approved the Toxic Substances Control Act, but neither chamber had voted on the conference report.

A.2.1.5 OSHA CONSIDERATIONS (Cont'd)

Toxic Substances Control legislation would permit more effective control over hazardous chemicals in the workplace by placing the responsibility for identification on the producer. Identifying dangers at the outset is less costly and more efficient than discovering them after the fact. Even with this legislation, OSHA must still act vigorously to meet its regulatory and inspection obligations. Without it, OSHA should set and enforce standards for employers to end the practice of unnecessarily exposing workers to known hazardous substances.

RECOMMENDATION: Determine the actions necessary for compliance with the Toxic Substances Control Act which was enacted on 12 October 1976 and Federal Standard 313A which was promulgated on 4 June 1976.

A.2.1.6 PERSONNEL CONSIDERATIONS

Personnel considerations are important factors in the application and removal of marine coating systems. They include not only manpower requirements, but personnel training and safety as well. Each of these factors may vary depending upon the type of coating system employed, the methods of application and removal, and the time allotted to accomplish the application and removal processes.

At present, replacement of a hull coating at a naval shipyard is accomplished by Shop 71 personnel generally over a period of several weeks during a ship's regular overhaul period. This type of work schedule permits the use of a minimum number of personnel engaged in work over a relatively long period of time. Replacement of a coating system in this manner has several disadvantages, which include the following:

- Abrasive blast operations generate large amounts of dust and often inhibit the performance of other exterior hull maintenance while the blasting is in progress.
- Shop 71 personnel are often hampered by interference from other shipyard tradesmen who are performing maintenance on both the exterior and interior of the hull. A typical example, cited by the Shop 71 General Foreman at Norfolk Naval Shipyard, is the interference of welders doing hot work on the hull plating inside the ship during or after the time painters have applied the new protective coatings to the exterior of the hull. Heat from welding causes the paint to blister, necessitating replacement of the coating in the damaged area.
- Delays in the application process are sometimes encountered due to the non-availability of support services (e.g., crane service) at the times required.

AD-A061 898 ADVANCED MARINE ENTERPRISES INC ARLINGTON VA F/G 13/10
SHIP UNDERWATER MAINTENANCE, EVALUATION, AND REPAIR (SUMER) MAS--ETC(U)
FEB 77 N00024-76-C-4543
UNCLASSIFIED NAVSEC-6136-77-9 NL

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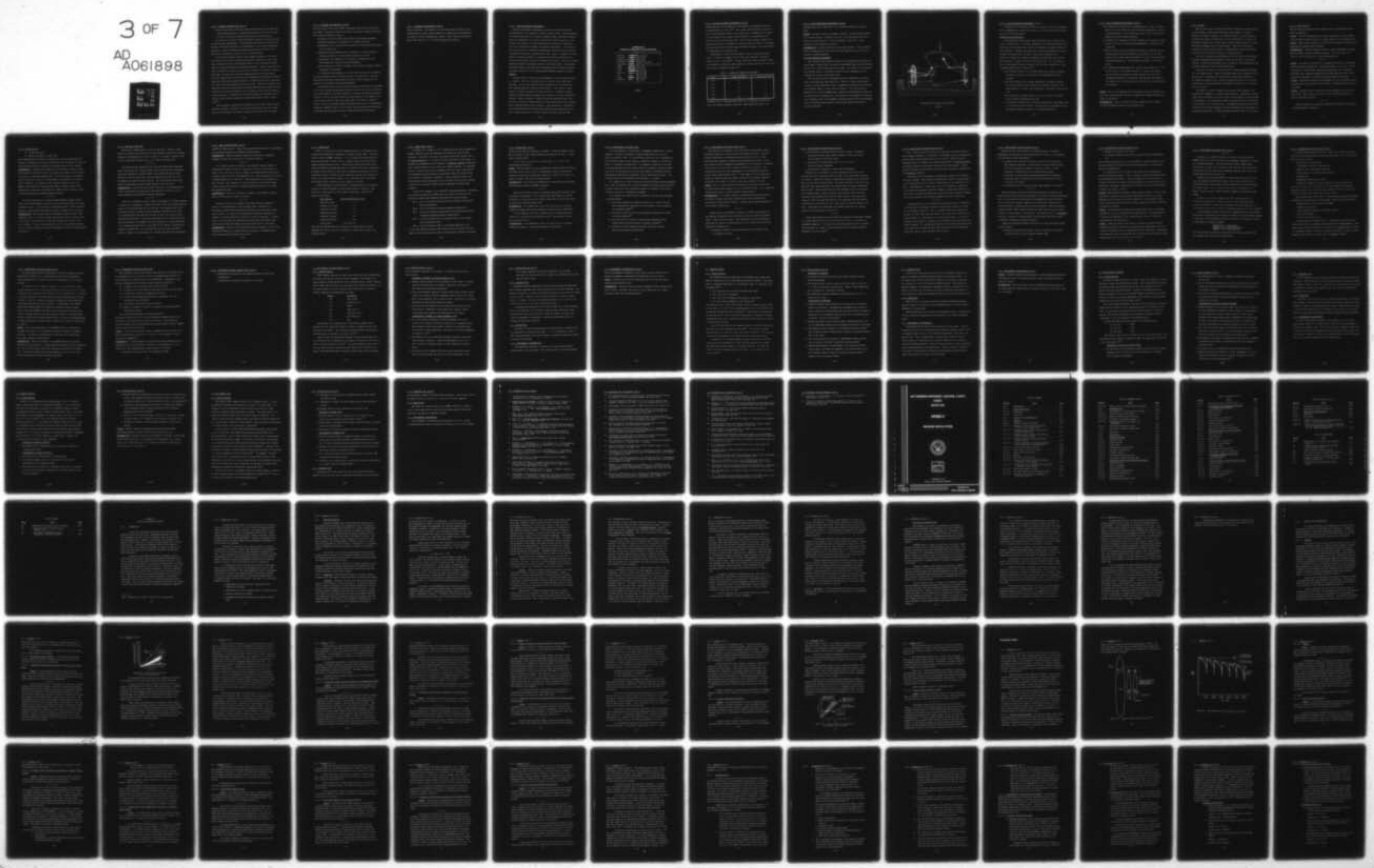
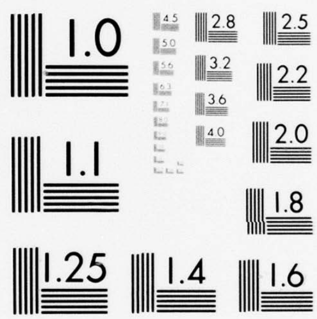




MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

A.2.1.6 PERSONNEL CONSIDERATIONS (Cont'd)

- Painters and blasters must work around such obstacles as soil chutes and steam condensate drains. Drydocked ships require the use of their head facilities and galley equipment during regular overhaul periods.

The concept of "Pit Stop" drydocking should be examined as a possible means of averting these disadvantages. The procedures described below would serve to maximize efficiency and minimize time requirements in hull coating replacement operations. Specific equipment requirements associated with the "Pit Stop" method will be discussed in section A.2.1.7 of this appendix.

If the desired interval between a ship's regular overhauls is six years, for example, but the vessel's antifouling coating is effective for only three years, drydock the ship at the three-year point in a dock specifically designated for coating replacement and equipped accordingly. Employ a large force of Shop 71 personnel to replace the vessel's hull coating in the shortest possible time frame. No other work would be performed during the "Pit Stop" period. The ship's company would be required to use shoreside head and galley facilities during the blasting and painting operations, eliminating the need for cumbersome soil chutes and steam condensate drains on the hull. Under such conditions, the Paint Shop Production Superintendent at Norfolk Naval Shipyard estimated that the entire hull of an attack submarine could be blasted to bare metal and painted in a three-day period. Similarly, the hull coating systems on a destroyer and an aircraft carrier could be replaced in five-day and two-week periods, respectively[23].

During regularly scheduled ship overhauls, the "Pit Stop" concept could be employed as follows: designate a time period, ideally after all other repair work has been completed, when Shop 71 personnel may abrasive blast and paint

A.2.1.6 PERSONNEL CONSIDERATIONS (Cont'd)

the entire hull of the vessel without interference from any of the other shipyard trades. During this period, ensure that the necessary drydock services are at the complete disposal of Shop 71.

Utilization of the "Pit Stop" method offers the following advantages:

- Coating replacement is accomplished in a minimum time frame.
- Uniformity of the coating system is achieved by uninterrupted application over the entire hull.
- Abrasive blasting operations may be conducted as a single evolution, reducing the amount of clean-up effort required in the dock.
- Considerable fuel savings can be realized by refurbishing a ship's anti-fouling hull coating at interim drydockings.
- More efficient use of Shop 71 manpower can be achieved through systematic scheduling of drydockings.

It is believed that employment of the "Pit Stop" method could be effected at naval shipyards without an increase in Shop 71 manning levels. Training requirements and safety considerations would also remain unchanged with the adoption of this method of coating refurbishment.

As mentioned earlier in this section, personnel considerations are dependent on the type of marine coating system employed as well as the method of application utilized and the time frame allotted to accomplish the coating replacement evolution. Of the five marine coating systems discussed in this appendix, two utilize cuprous oxide as their toxic agent while three employ an organotin biocide. Due to the personnel hazards associated with the use of organometallic substances, adoption of any one of the latter coating systems would necessitate a thorough training program on product handling procedures and personnel

A.2.1.6 PERSONNEL CONSIDERATIONS (Cont'd)

safety precautions. Procurement of the necessary safety equipment and the implementation of various safety measures are overhead costs associated with the adoption of these organometallic systems. These items are discussed in detail under Section A.2.1.7, Facility/Equipment Requirements.

A.2.1.7 FACILITY/EQUIPMENT REQUIREMENTS

Facility and equipment requirements are major factors which should be considered prior to the adoption of a marine coating system. Some requirements are universal and apply to all types of coating systems, while other requirements vary depending on the specific physical and chemical properties of the coating. The length of the time frame allotted to replace the coating on a ship's hull also affects equipment and facility requirements. As discussed in the previous section on personnel considerations, the Navy currently utilizes a minimal work force over a long period of time. Under the proposed "Pit Stop" method of coating replacement, a large work force would be employed over a relatively brief period of time to accomplish the evolution. As can be expected, additional equipment requirements exist for the latter method. The following paragraphs identify these additional requirements and the specific equipment requirements peculiar to hull coating systems employing organotin biocides.

DRYDOCKS

The major facility required in the replacement of any hull coating system is a drydock. There are 37 graving docks in inventory in the eight naval shipyards. Ten of these docks have been obsoleted due to the lack of deep draft docking capability required by modern ships[1]. That leaves 27 naval drydocks to support the Navy's 484 active ship fleet. Commercial shipyard drydocks are being used, and presumably will continue to be used, to absorb this workload. Figure I contains a listing of some Navy ships/ship types and a portrayal of the basic planning factors for the periods between ship overhauls and the nominal duration of the overhauls. This information is contained in Navy ship maintenance policy instructions maintained and promulgated by the Chief of Naval Operations. The chart itself was extracted from the Navy

EXAMPLES OF OVERHAUL/OPERATING CYCLES (MONTHS)

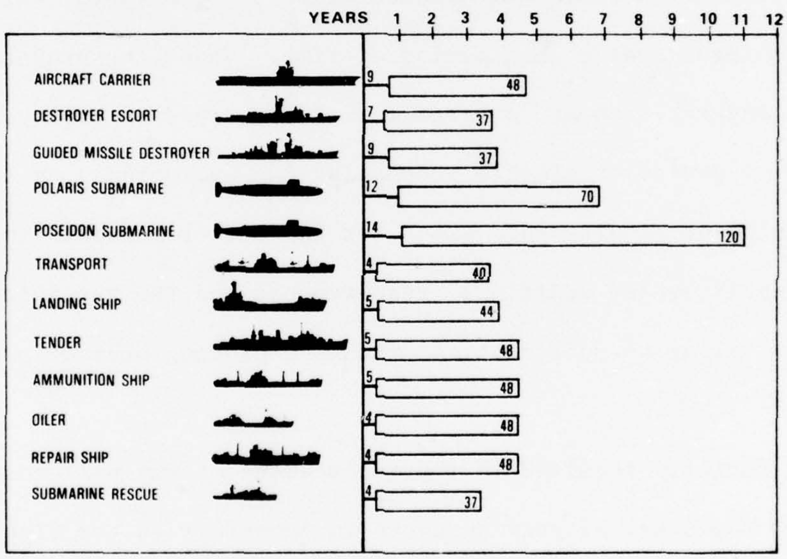


FIGURE I

presentation before a Subcommittee of the Committee on Appropriations, House of Representatives in June 1975[25]. The average interval between overhauls of these various ships/ship types is about four years. Dividing the total number of active ships by this average interval indicates that approximately 121 overhauls must be performed each year. From a marine coatings standpoint, all ships should actually be drydocked at three-year intervals which is the maximum effective service life of present day antifouling coatings. This would require the drydocking of 164 ships per year!

Unfortunately, the Navy has been unable to meet the desired overhauls cycles. In FY76, for example, only 76 ships were overhauled. The Navy's target for FY77 is 105 ships[26]. Failure to meet the required overhauls cycles has resulted in a backlog of ships overdue for overhaul over the last five years. This backlog is depicted in Table IV[26].

TABLE IV - BACKLOG OF OVERDUE SHIP OVERHAULS

End-FY	Number of Ships	Percent of Fleet
1971	17	2
1972	27	4
1973	26	5
1974	47	9
1975	71	14
1976	69	14

Although there are many underlying causes for the backlog, the three most obvious are shipyard manpower limitations, O&MN funding constraints, and

A.2.1.7 FACILITY/EQUIPMENT REQUIREMENTS (Cont'd)

extended duration of overhauls due to the increasing complexity of modern ships.

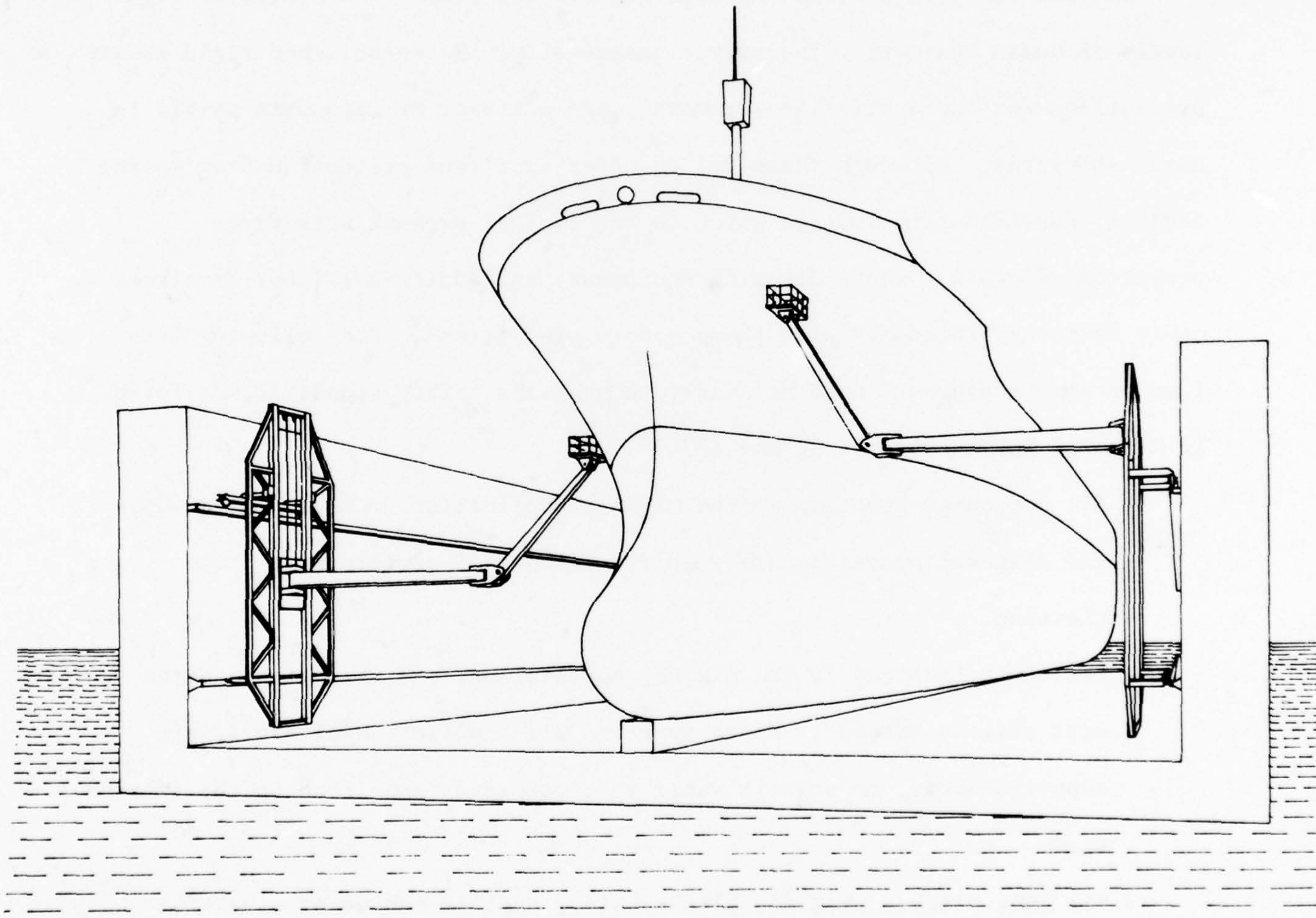
FINDING: The Navy is unable to overhaul the Fleet at the periodicity desired due to several factors. One major constraint is the shortage of deep draft drydocks at naval shipyards. It has been publicly stated that a large "backlog" of ship overhauls now exists[1].

RECOMMENDATION: Consider the construction of more drydocks. Study the possibility of deepening those docks which have been obsoleted due to the lack of deep draft docking capability.

"PIT STOP" METHOD OF DRYDOCKING

The backlog of ship overhauls caused by the aforementioned conditions has forced ships to remain afloat for periods considerably longer than the effective service life of their antifouling hull coatings. As a result of the increased hull fouling, there is a substantial increase in fuel consumption for the remainder of the ship's operational cycle.

The "Pit Stop" method of drydocking should be considered as a possible means of averting these added fuel costs. Ideally, a drydock devoted specifically to coating replacement would be equipped with hydraulically controlled work platforms similar to those shown in Figure II. The unit pictured is manufactured by a Dutch company known as Maastrichtse Machinefabrick Delnoz bv. As advertised by the manufacturer, the platforms can be equipped with abrasive blast equipment, paint spray equipment, and high pressure water spray equipment. Such an installation would greatly facilitate and expedite blasting and painting operations.



HYDRAULICALLY CONTROLLED WORK PLATFORMS

FIGURE II

A.2.1.7 FACILITY/EQUIPMENT REQUIREMENTS (Cont'd)

In addition to the hydraulic platform, an increase in utility requirements such as compressed air, electricity, water, etc., would result from the employment of the "Pit Stop" method.

Organotin Antifouling Paints

Antifouling paints which employ organotin biocides have relatively high levels of human toxicity. The Navy, consequently, has established rigid safety precautions for the application, removal, and disposal of organotin paints in naval shipyards. Although these paints offer excellent protection from marine fouling, consideration must be given to the capital expenditures for protective clothing, waste disposal equipment, and additional labor requirements necessary to comply with these safety precautions. The following is a list of some measures deemed necessary to meet the safety standards set forth in NAVSHIPS NOTICE 9190 of 28 May 1974[11].

- All personnel involved in the mixing, application, removal, clean-up, and disposal processes are required to wear disposable protective clothing.
- Personnel involved in the mixing, application, and removal processes must utilize Bureau of Mines approved air supplied respirators, air supplied hoods, or organic vapor respirators as specified in the instruction.
- All keel blocks, staging, planks, etc., must be masked or otherwise covered during the application process.
- In accordance with the safety precautions promulgated, normal application will be made by roller or brush. This constraint considerably increases the number of manhours required in the application process.

A.2.1.7 FACILITY/EQUIPMENT REQUIREMENTS (Cont'd)

- All exterior hull work on the ship being painted, as well as on other ships in the same drydock, must cease during the application or removal of organotin paints. Such a precaution results in loss of productive manhours and extends drydock durations.
- To minimize the spreading of airborne organotin dust during the removal process, the use of wet abrasive blasting methods is specified in the instruction.
- The waste abrasive grit and abraded coating which accummulate in the drydock during the removal process must be gathered in a wet state, placed in steel drums, sealed and buried in a Class I sanitary landfill or approved dumping site. Such disposal requirements are extremely costly.
- All painting and masking materials, rollers, cans, brushes, etc., must also be sealed in steel drums and buried. To reduce the volume of material and hence the number of drums required, the instruction recommends procurement of a horizontal solid bulkhead type compactor. The compactor that is procured must be used only for antifouling paint waste disposal.

FINDING: The cost of complying with the prescribed safety precautions associated with the application, removal, and disposal of organotin antifouling paints in substantial.

RECOMMENDATION: This cost should be carefully weighed with the benefits derived from employing organotin antifouling paints.

A.2.2.1 POLICY

When one rises above the detail level which is discussed in other portions of this Appendix, certain salient findings become prominent. Long life underwater coatings are needed as one important measure to allow extension of the drydocking interval of Navy ships. The key requirement is to defeat the attachment of marine life to reduce shaft horsepower requirements and to avoid producing hydrodynamic noise in sonar systems. (Long life anticorrosive coatings are already state-of-the-art.) Camouflage and reduced sonar reflectance would also be valuable attributes of coating material.

The focus of research and development must be upon long life antifouling coatings containing marine pesticides to target the spectrum of phyla which threaten. Research and development effort is largely a multi-disciplinary task involving chemistry and marine biology disciplines.

Selection of coatings for service use will consider alternatives coming out of the RDT&E process. Among the parameters which must be examined in this selection are: availability of raw materials, manufacturing capability of the commercial production base, industrial engineering aspects of the surface preparation and coating application, performance in service use, and environmental constraints.

The amount of activity on-going in the marine coating community, both scientific and commercial, is prolific and diversified. Considerable time and effort would be required on the part of Navy coating engineers to keep informed of developments. The International Committee on Marine Corrosion and Fouling is an important one of these activites. The NAVSEA Steering Group for Surface Preparation and Painting Equipment and Methods Standardization Subcommittee is performing valuable work. The Manufacturing Technology Projects of the Naval

A.2.2.1 POLICY (Cont'd)

Material Industrial Resources Office already contain on-going efforts which should be monitored.

FINDING: The key requirement is for a marine antifouling coating to defeat a wide spectrum of marine phyla and to remain effective for an extended period.

FINDING: Other valuable properties of a long life antifouling coating would be camouflage and reduced sonar reflectance.

RECOMMENDATION: Fund and otherwise continue to support development of organo-metallic polymer coatings at DTNSRDC, Annapolis. This work offers real potential for achieving long life antifouling properties.

* * * * *

FINDING: The process of selection of a coating for service use is a decision process separate from RDT&E work. Among other things, this decision involves availability of raw materials, manufacturing capability of the commercial production base, industrial engineering for surface preparation and coating application, performance in service use and environmental constraints.

FINDING: Constraints deriving from environmental and from occupational health considerations have increased by several orders of magnitude during the past five years.

FINDING: On-going activity in the marine coating community is prolific and diversified. This activity is of value to Navy coatings programs and it should be monitored routinely.

* * * * *

There are currently no prescribed standards which represent the maximum acceptable degrees of fouling on:

A.2.2.1 POLICY (Cont'd)

a) various ship types

b) specific portions of a ship's hull.

Such standards should be based on a comparison of the costs associated with brushing or replacing a ship's hull coating versus the increased fuel costs and other deleterious effects experienced at different levels of hull fouling.

RECOMMENDATION: Establish such standards for use fleetwide, bearing in mind that fouling on a destroyer tender, for instance, is no where near as critical as fouling on a high speed combatant ship. By the same token, an acceptable level of fouling on a ship's hull proper might be unacceptable on its sonar dome or propeller. The results of tests recently conducted on the U.S.S. HAROLD E. HOLT (FF-1074) to determine the effects of marine fouling on the performance of a Navy ship for selected hull regions could be used as a guide in establishing maximum acceptable degrees of fouling.

* * * * *

The proper application of a marine coating system has perhaps as much effect upon the performance and service life of the system as does the coating formulation itself. For this reason a considerable amount of effort should be devoted to assuring proper application of marine coatings in naval shipyards.

RECOMMENDATION: Close liaison should be maintained between the Navy's R&D community, which is striving to develop new and better marine coating systems, and the Shop 71 painters who are tasked with applying these systems at the naval shipyards. Liaison can be acomplished via the existing NAVSEA Steering Group for Surface Preparation and Painting Equipment and Methods Standardization Subcommittee.

A.2.2.2 WHAT CAN BE DONE NOW?

Nelson said, "England needs a victory at this hour." Whereas a prime purpose of the Master Plan may well be to give strategic direction to improving underwater ship husbandry over the next decade, it is proper to identify items on which action might proceed at once, or at least in the near term.

* * * * *

The extant military specification for red vinyl underbottom antifouling paint, Navy Formula 121, is MIL-P-15931B; and for the black vinyl boottopping paint, Navy Formula 129, is MIL-P-16189B. These specifications are being modified so that the solvent will come into compliance with Rule 66 of the Los Angeles Air Pollution Control District. The solvent methyl normal butyl ketone is being used in place of methyl isobutyl ketone and xylene.

RECOMMENDATION: Complete the work, already in process, of re-formulating the cuprous oxide based antifouling paint, Navy Formulas 121 and 129, so as to obtain compliance with hydrocarbon emission limitations.

* * * * *

There is a considerable consensus that the performance of coatings currently in service use is inadequate. However, since about 1961, the feedback reporting system via the Docking Report has not been used. The reasoning which led to cancellation of the "as docked" coating performance evaluation is not known. It is speculated that the effort was too great to fill out a form for every ship which was drydocked. This would be especially true if the person who was making observations on performance had little expertise in coating technology or in recognizing marine biota, but was forced by the system to perfunctorily complete a standard form. It is believed that service coating evaluation should be resumed on a limited basis, for selected ships which have experienced

A.2.2.2 WHAT CAN BE DONE NOW? (Cont'd)

extended waterborne service. These evaluations should be made only by individuals with recognized expertise in coatings and marine biology.

RECOMMENDATION: Resume performance appraisal or evaluation of underwater coatings on active fleet ships in the "as docked" condition.

* * * * *

It is timely to update the chapter of the NAVSHIPS Technical Manual on "Preservation of Ships in Service". The date of the most recent edition is January 1970. Since that time, for example, the epoxy-polyamide anticorrosive coatings of MIL-P-24441 have been adopted for use. They were approved for service by NAVSHIPS NOTE 9190 of 9 June 1972. Other information in this chapter also needs updating. The foregoing is a further indicator of the overload being carried by the limited number of coatings engineering personnel in the Naval Ship Engineering Center.

RECOMMENDATION: Update and re-publish the chapter of the NAVSHIPS Technical Manual on "Preservation of Ships in Service".

* * * * *

During this study it was learned that Hittman Associates expected to deliver to the Environmental Protection Agency about 1 November 1976 a Development Document regarding effluent limitations from drydocking and ship repair activity. On reason for obtaining early information regarding this Document is to make constructive criticism to the EPA if necessary. A second reason is to gain lead time planning in the likely event that drydock sump water effluent limitations might require particulate filter installations.

RECOMMENDATION: Obtain from the Environmental Protection Agency a copy of the Development Document for proposed effluent limitations to navigable waters from drydocking and ship repair point sources.

A.2.2.3 NEEDED RDT&E

There is a clear need to provide funding support and to otherwise foster research and development of organometallic polymer coatings (OMP). This work is now at hand at DTNSRDC, Annapolis. It is a coating which holds promise of defeating the growth of marine life for a nominal five year period by use of chemical marine pesticides alone. (Other salient systems would employ thick films and mechanical brushing under water.) The OMP's being given consideration at present are the product of many years of preparatory and supportive effort during which scores of similar but less effective materials were rejected for cause in an orderly selection process. It is vital that this work on OMP's, now nearing fruition, should be carried through to conclusion.

In 1969 Freiberger and Horbund report[45] interesting work on the relative toxicity of selected compounds to second stage nauplii of barnacles. They measured the time required to kill one-half a population. Results were summarized as follows:

Toxic Compound	Time for 50% Mortality, mins.
tributyltin oxide	5
triphenyltin chloride	23
tributyltin fluoride	23
triphenylead acetate	40
tributyltin sulfide	64
tributyltin resinate	140
cuprous oxide	more than 240

This early work demonstrated the relative toxic effectiveness of certain compounds, but did not, and was not intended to, assess the life span of an antifouling paint.

A.2.2.3 NEEDED RDT&E (Cont'd)

In November 1972, Dyckman, et al[27], reported work upon forty organometallic polymers (OMP) which they had synthesized and tested for marine fouling resistance. These OMP's are unlike conventional antifouling coatings, which are physical mixtures of: (a) rosin, (b) vinyl resin and (c) toxic agent. In the OMP's the organometallic toxic compound is chemically combined (polymerized) with a resinous material so as to form a new chemical compound. One advantage of this is control of the rate of leaching of the toxic agent; leaching rate of conventional antifoulant paint is unnecessarily high and wasteful during early months of its exposure in seawater. Another advantage of OMP's over state-of-the-art antifouling paint is that the rosin in the latter is actually a food source for bacterial slime, precursor organisms for macrofouling barnacles.

In April 1974, Dyckman, et al, reported[10] continuing progress in evaluating the antifouling performance of OMP's and on the basis of field trial data selected five OMP's which warranted formulation into marine coatings:

OMP 1: poly (tri-n-butyltin methacrylate/tri-n-propyltin methacrylate/ methyl methacrylate)

OMP 2: poly (tri-n-butyltin methacrylate/methyl methacrylate)

OMP 3: poly (tri-n-butyltin methacrylate/tri-n-propyltin methacrylate/ tribenzyltin methacrylate/methyl methacrylate)

OMP 4: the tri-n-butyltin and tri-n-propyltin ester of poly (methyl vinyl ether/maleic acid)

OMP 5: the tri-n-butyltin ester of cross linked methacrylic acid.

At this time immersion testing of OMP resins by Navy has continued for more than four years and samples have shown no marine growth, neither microfouling

A.2.2.3 NEEDED RDT&E (Cont'd)

(slime) nor macrofouling (barnacles, tubeworms). During the summer of 1975, OMP 1 was added to panel testing program being conducted for the U. S. Coast Guard at Daytona Beach[6].

In 1976, work was initiated to formulate OMP's 1, 2, 4 and 5 into antifouling paint material.

FINDING: The development work upon organometallic polymers (OMP's) which has been under way for several years is comprehensive, orderly and holds real promise for producing an antifouling coating with a service life span of at least five years. This work is nearing fruition.

RECOMMENDATION: Fully support the RDT&E work for formulating and evaluating OMP antifouling coatings at DTNSRDC, Annapolis.

* * * * *

There would be military value in submarine coatings which provide visual concealment or camouflage. Also, coatings which show promise for reduced reflectance of sonar waves in the frequency range used by search sonar would be valuable for submarine applications.

RECOMMENDATION: As an RDT&E task, examine the possibility of developing submarine coatings which provide camouflage and reduced sonar reflectance.

For both submarine and surface combatant ships, coatings having the capability of substantially decoupling the ship's structureborne radiated noise would have merit.

RECOMMENDATION: As an RDT&E task, examine the possibility of developing underwater coatings to reduce structureborne radiated noise.

A.2.2.4 EFFECTIVENESS EVALUATION PLANS

It is now necessary to discuss what in management systems terms is called appraisal. How well do underwater coatings systems perform the function which is required of them? If a few different systems are to be considered for use, how does a person go about making a comparative judgment on the merits of each? It is generally conceded that: (1) atmospheric conditions at the time of coating application and (2) operator skill and technique in surface preparation and in coating application may have equal weight in determining service effectiveness along with the composition of the coating material itself. How may these factors be incorporated in the appraisal of a coating?

As a general note, it must be said that existing materials perform remarkably well. When one considers that a few mils thickness of coating material suffices to protect steel plate from corrosion in seawater for upwards of seven years, it must be set down as a remarkable achievement.

It is observed that several types of evaluation tests are being performed on coating systems:

- panel tests displayed in offshore locations (i.e., within 100 yards from the shoreline), especially for the evaluation of new coatings in the development stage[28, 6]
- patch tests on ships in which newly developed coatings may be tested in service conditions[11]
- long term tests of a variety of anticorrosion coatings on steel pilings driven 100 yards offshore at Dam Neck, Virginia[29]
- a battery of quality assurance provisions and tests contained within the procurement specifications

A.2.2.4 EFFECTIVENESS EVALUATION PLANS (Cont'd)

Most especially recommended to those who wish to pursue marine coating performance evaluation in further detail are References 28 and 6. Battelle Columbus Laboratories is performing evaluation tests for the U. S. Coast Guard upon panels immersed in seawater near Daytona Beach, Florida. In the early spring of 1975, a comprehensive examination of the performance of eighteen coating systems was made after 51 months of immersion in seawater. (The coating which was rated "truly outstanding" for its antifouling properties at this time was Navy Formula 121/63.) In the summer of 1975, an additional twenty-two coating systems were added to the list of the original eighteen, raising the total number of coating systems under evaluation to forty.

FINDING: The U. S. Coast Guard has a stated goal of five-year service life for marine antifouling coatings to use on its ships and buoys. It is sponsoring long-term panel tests to evaluate premium coating material.

RECOMMENDATION: As a minimum, maintain continuing liaison with and monitor the results of panel tests being conducted by the Coast Guard/Battelle Laboratories at Daytona Beach, Florida. Consider joint funding sponsorship of this valuable on-going work.

* * * * *

Another system for performance evaluation of marine coatings which has been employed is applying them to portions (or even the complete underwater body) of ships in active service. This scheme has the obvious advantage of subjecting the coating to conditions which are not simulated by panel tests. Among these conditions are:

- mechanical vibration of hull panels induced by the propeller and by pounding sea forces.

A.2.2.4 EFFECTIVENESS EVALUATION PLANS (Cont'd)

- the variation in marine biological life due to depth. Chlorophyll bearing phototrophic algae require sunlight, and are not found on the flat bottom of deep draft ships.
- high velocity, turbulent water flow, like that found in the wash of ships' propellers.
- the frictional resistance to ships' power requirements.

Reference 30 is an example of a study performed a decade ago on the increased frictional resistance effects on ships' power requirements caused by hull fouling. Among other things, it showed that for destroyer type ships with hulls not yet fouled by marine growth, frictional resistance to motion was less when vinyl resin antifouling paint was used than when hot plastic antifouling paint was used. Another observation was that although the vinyl resin paints had a somewhat higher fouling rate during their lifetime, their frictional resistance never exceeded that of the hot plastic system. These tests were conducted in the time frame 1965-1967, and it is speculated that they may have contributed to the decision for use of vinyl resin antifouling coatings in the Fleet. Nonetheless, they demonstrate the ultimate evaluation of a coating system, full scale testing in service use.

* * * * *

Another method which has been utilized for evaluation of underwater coatings is to apply them on the hull of a ship on active service in a test patch of reasonable dimensions. In the past few years this method was used to evaluate the performance of a number of antifouling paints which contained organotin compounds as the toxic agent[11].

A.2.2.4 EFFECTIVENESS EVALUATION PLANS (Cont'd)

(N.B. At this point in the narrative of the study, having mentioned the word organotin compounds, it is necessary to distinguish them from organometallic polymers (OMP's) which comprise the work now in hand at DTNSRDC, Annapolis. Organotin paints, for example, Mare Island Formula 1020A, are physical mixtures containing tributyltin oxide and/or tributyltin fluoride compounds. Organometallic polymers are large molecules in which these tributyltin compounds have been chemically combined.)

Patch tests offer the advantage of subjecting a coating to the realities of service exposure. They provide an opportunity to compare the performance of a test coating with that of a control coating applied to the remainder of the hull. A disadvantage of a patch test is that it is necessary to employ the use of divers and underwater television cameras for inspection purposes; it is not practical to remove the sample from the water and make a quarterly examination of the condition of the coating as might be done with a panel test.

* * * * *

During this study it was learned that the National Bureau of Standards is in the process of evaluating a variety of anticorrosive coatings in a field test at Dam Neck, Virginia[29]. This is a planned fifteen-year program, and in 1976, the first eight years had elapsed. The twenty-three coating systems being evaluated are representatives of three general groups: (a) metallic coatings, (b) non-metallic coatings and (3) non-metallic coatings applied over metallic primers. The coatings were applied to steel H-beam pilings which were then jetted into the sandy shoreline where the water depth is approximately seven feet, that is, about 100 yards from the beach.

A.2.2.4 EFFECTIVENESS EVALUATION PLANS (Cont'd)

Despite that the stated purpose of the National Bureau of Standards' investigation is addressed to steel pilings and not to ships, it is considered that the work has useful applicability.

- evaluation is being made of protection of steel in the splash zone. This simulates conditions in the vicinity of a ship's waterline where the hull is alternately exposed to air and salt water. A ship's waterline is frequently an area of incipient hull pitting.
- the variety of anticorrosive coatings being employed is impressive. Continuing study of the NBS results may avoid duplication of effort on the part of the Navy.
- the objective point of view of the NBS lends credence to the results.

* * * * *

Quality assurance provisions and testing requirements contained in the Military Specifications used for procurement are a means for evaluating effectiveness. Such tests may have deficiencies for estimating the long term service life of a particular coating. However, they provide vital indicators from which satisfactory, extended service life may be inferred. Military Specification MIL-P-23236, "Paint Coating Systems, Steel Ship Tank, Fuel and Salt Water Ballast" is a good example of this approach. This specification is a performance type one, in contrast to specifications for ship bottom paints which specify the specific ingredients and their quantities.

Among the accelerated laboratory tests which are specified in MIL-P-23236 are such items as:

- immersion resistance during twenty cycles of exposure to salt water, boiling salt water, and hot seawater pressure spray

A.2.2.4 EFFECTIVENESS EVALUATION PLANS (Cont'd)

- adhesion of coating by knife tests
- an 18-month shipboard service test to evaluate coating performance in use.

After successful completion of the tests specified, a qualified products list has been established listing trade names and manufacturers of products which have met the requirements.

It is admitted that the coatings of MIL-P-23236 are not formulated to possess antifouling properties. They do, however, provide anticorrosion protection from immersion in seawater. They are brought into this discussion to illustrate the point that there is working precedent for relatively short term evaluation of underwater coatings which are intended to have a life expectancy of eight to ten years in service.

FINDING: Naval shipboard underwater coating systems presently in use are being specified by "cookbook" type procurement specifcations; that is, the exact ingredients and the quantity of each is spelled out. This procedure intrinsically fixes the service life of the coating, assuming that proper application techniques are followed.

FINDING: The anticorrosive coating specification, MIL-P-23236, is a working precedent for the use of performance type specifications. The government does not specify the ingredients of the coating material, which is formulated proprietarily by the manufacturer.

FINDING: During the course of this study no instance was observed wherein extended antifouling properties of a coating could be demonstrated and proven by means of laboratory tests or extrapolation of short term tests. Advertising and proprietary claims are being made that a five-year life antifouling coating already exists based on abbreviated test results[31].

A.2.2.4 EFFECTIVENESS EVALUATION PLANS (Cont'd)

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Some effort was expended looking into the use of the Docking Report, NAVSHIPS 9020-2, as a tool for evaluation of underwater coatings and a vehicle for recording performance. This was perceived as being valuable effort, because after all panel tests, laboratory tests, and patch tests results have been studied, the real bottom line for appraisal remains: How well did the coating system perform in service use?

A sampling of ten Docking Reports of recent date from the files of the Naval Ship Engineering Center was perused. Each of these reports was of a docking which had occurred during a regular overhaul, not an interim docking for voyage repairs. A cross section of fleet ships was included in the sample - aircraft carrier, surface combatant, submarine and wooden hull minesweeper.

In addition to the above sampling, the files of docking reports at Norfolk Naval Shipyard were examined in the hope that coating performance could be evaluated over a long term by looking at the coating appraisals of one particular ship in three successive drydockings extended over, say, a decade[23].

It was learned that twenty years ago very considerable effort and attention were devoted to appraising and recording the condition of ship underwater coatings. At that time, the Docking Report consisted of a series of form sheets, of which the following were especially germane:

NAVSHIPS 223-1, Docking Report
NAVSHIPS 223-2, Coating Application
NAVSHIPS 223-8, Wooden Hull Data

All of these forms are labeled as having been newly revised in January 1955, and it appears that they were in use until 1961.

A.2.2.4 EFFECTIVENESS EVALUATION PLANS (Cont'd)

On the 1955 Docking Report, Form 223-1, nearly half the page was used to record the following information pertaining to performance of the coating found upon the ship "as docked":

- Date and place last undocked
- A synopsis of the ship's operating area
- Number of days under way/not under way
- Navy formula of coatings previously applied
- Touchups made
- Experimental applications, if any
- Adjective statement of coating condition in various bottom areas

Also, on the reverse side of Form 223-2, the Coating Application Report, a diagramatic sketch of the ship bottom was furnished on which the extent and location of fouled and corroded areas could be marked.

On the obverse side of Form 223-2, a quite detailed statement was reported regarding the coating applied at this docking. Among the data reported were:

- Manufacturer of coatings and batch numbers
- Dates of manufacture
- Dates applied, temperature and weather condition
- Dry film thickness
- Time interval between coats

A revised format was adopted in 1961. The elements of information mentioned in the above two paragraphs were deleted from the Docking Report. Since 1961, a report is made identifying the coating which is applied during a particular drydocking; however, no report is required concerning the condition of the underwater paint system of the ship in the "as docked" condition.

A.2.2.4 EFFECTIVENESS EVALUATION PLANS (Cont'd)

The Docking Report Form was revised again in 1967 and assigned a new Form Number 9070-1 (Revised 1-67). Changes made did not affect the underwater coating system, and the "as docked" condition of bottom paint is not routinely reported.

In studying the Navy's appraisal practices, it was observed that bottom coating evaluation work is now being performed for special cases but is recorded and reported more informally than through use of the Docking Report. For example, in minutes of meetings of the Steering Group, Surface Preparation and Painting Conference, there are a number of references to underwater coating appraisals having been made upon Navy ships in drydock. A Docking Report from SUPSHIP Newport News regarding SSBN 617 in March 1975 included a Painter's Report using a local form (NNS&DDCO Form 2051) which provided adjective descriptions of marine fouling conditions with identification by phyla. The Superintendent Painter at Norfolk Naval Shipyard mentioned that, as a matter of professionalism, he normally inspects the coating systems of ships as they return to drydock from sea service.

FINDING: Use of the Docking Report, Form NAVSHIPS 9070, as a mechanism for recording the condition of the underbottom coating "as docked" was abandoned about 1961. At present the Docking Report records only the coatings which were applied during the drydock period.

RECOMMENDATION: Draw up a form sheet in the NAVSHIPS 9070 series entitled Underwater Coating Evaluation. Include among the reportable items of information most (all) of those elements which were contained in the Form 223 of vintage 1955. Utilize only observers with coating expertise to fill out this form, rather than perfunctory remarks from casual observers.

A.2.2.5 DEVELOPMENT PROGRESS TRACKING PLANS

When this Master Plan has been drawn up and published in the spring of 1977, it is expected that it will contain a group of recommendations which will win official approval and which will need to be implemented. Assuming that, some of these recommendations would modify ongoing programs and practices:

(a) in RDT&E projects, including those sponsored by ONR

(b) in design work, in ship specifications and in military specifications

(c) in industrial production equipment and facilities

(d) in ship overhaul scheduling intervals for both depot level and intermediate level maintenance

(e) in personnel allocations to naval activities

(f) making it necessary to re-write a multitude of existing directives and technical manuals

(g) requiring reprogramming of funding allocations.

The question is who will see to it that the approved recommendations are put into effect. Who will bring into concert the efforts of the multifarious activities whose duties and responsibilities, already properly assigned, impinge upon the goals of the Master Plan?

FINDING: At such future time when certain recommendations of this Master Plan have received approval, there will be a need for a single manager to assure that they are implemented.

RECOMMENDATION: A Program Manager in the Naval Sea Systems Command should be designated at the executive agent to implement the recommendations of this Master Plan. His responsibilities should include the following:

- drafting a policy directive to be promulgated by OPNAV

A.2.2.5 DEVELOPMENT PROGRESS TRACKING PLANS (Cont'd)

- identifying fund resources in the budget necessary to foster these recommendations
- ascertaining and tracking the progress of the program.

A.3 NAVY FORMULA 150 SERIES/FORMULA 121/63

A.3.1 STATE-OF-THE-ART

These formulas constitute the Navy's most widely used hull coating system. The Formula 150 (series), the anticorrosive component of the system, is an epoxy-polyamide coating approved for use on underwater hulls, exterior topsides, bilges, tanks, and wet spaces (e.g. wash rooms, water closets, sculleries, etc.). The series consists of the six formulas listed below which are applied in different combinations depending upon the usage:

Formula	Description
150	Green Primer
151	Haze Gray No. 27
152	White
153	Black, Ro 1.8
154	Dark Gray, Ro 3.6
155	Dark Gray, Ro 6
156	Red

When employed as an underwater hull anticorrosive, single coats of Formulas 150, 151, and 154 are applied to produce a minimum total dry film thickness of 8.0 mils[32]. This coating has yielded excellent anticorrosion protection since its adoption by the Navy in 1972[23].

Formula 121/63, the antifouling component of this coating system, is a red vinyl paint that is applied over the Formula 150 (series) in two coats to yield a dry film thickness of 4 mils[32]. The coating employs cuprous oxide as its toxic agent and has a maximum effective service life of about 3 years. Where a black antifouling paint is specified, Navy Formula 129/63 is applied

A.3.1 STATE-OF-THE-ART (Cont'd)

as the antifoulant component of the system. Its effective service life is about one year.

ADVANTAGES OF FORMULA 150 (SERIES)/FORMULA 121/63

- Milspecs currently exist for both components of this system. A logistic chain for the manufacture, procurement, application, and removal of this system has already been established.
- From an environmental standpoint, Formula 121/63, which utilizes cuprous oxide as its toxicant, poses no signficant threat to man or the environment in the application, use or removal process. The product is currently registered with EPA's Marine Pesticide Division.
- The total dry film thickness of the coating system (12 mils) is relatively small in comparison to other marine hull coatings, thereby contributing little weight to the displacement of the vessel.

DISADVANTAGES OF FORMULA 150 (SERIES)/FORMULA 121/63

- Due to the chemical formulation of epoxy polyamides, each of the coatings in the Formula 150 series is supplied as two components which must be mixed, stirred, and allowed to stand for a prescribed period of time prior to their application. The potlife of the mixed components is 6 hours at 73°F[32].
- The service life of the antifouling coating is limited to three years under favorable conditions. Fouling has been known to occur in as short a period as 6 months, however, on ships operating in tropical waters.
- The cuprous oxide in Formula 129/63, the black antifoulant topcoat, tends to turn green when used on the top side of submarines. This

A.3.1 STATE-OF-THE-ART (Cont'd)

color change undermines the vessel's camouflage. As previously mentioned, the service life of this coating is considerably shorter than that of Formula 121/63.

A.3.2 TECHNOLOGY GAPS

Comparative studies conducted over the last several years have ranked the Navy's current underwater hull coating system as one of the best available. The Formula 150 series has exhibited superlative anticorrosive protection for periods of up to 7 years. Formula 121/63 has proven effective for periods ranging from 18 - 36 months. The major technology gap apparent in this system is the limited service life of the vinyl antifouling coating.

A technology gap apparent not only in this system, but in other systems as well, is the inability of the coating to stand up under conditions of high velocity water flow, such as the flow to which the rudder, sea chests, and other hull appendages are subjected. Protective paint systems tend to be scoured off under these conditions.

A.3.3 NEEDED RDT&E

The need for long life antifouling hull coatings that are compatible with our environment is recognized world wide. The U. S. Government, as well as many foreign governments and private industry, is presently conducting research to develop such coatings.

A.3.4 ENVIRONMENTAL CONSIDERATIONS

The antifouling component of the Navy's hull coating system employs cuprous oxide as its toxic agent. Since cuprous oxide is relatively harmless

A.3.4 ENVIRONMENTAL CONSIDERATIONS (Cont'd)

from an environmental standpoint, it will suffice to make reference to the general environmental considerations discussed earlier in this report.

FINDING: The Navy's current hull coating system is one of the best marine coating systems available today.

RECOMMENDATION: Continue to use the Formula 150/Formula 121/63 coating system until a system is developed which offers a major improvement (e.g. doubles the service life) over the existing system.

A.4 SEAMASTER SYSTEM

A.4.1 STATE-OF-THE-ART

The Seamaster System was developed by the Norwegian paint manufacturer JOTUN in consultation with the Ship Research Institute of Norway. The system, which is categorized generically as a chlorinated rubber, is comprised of the following coats[33]:

- one 0.6-0.8 mil coat of Securit Zinc-Rich Shop Primer
- four 4 mil coats of Vinyguard
- four 3 mil coats of Seamaster Antifouling on side bottom
- two 3 mil coats of Seamaster on flat bottom area

The effective service life of the Seamaster System in commercial applications is advertised to be 4 to 5 years, requiring three or four reactivations of the antifouling coating during that time period[34]. Reactivation is accomplished by removing the outer layer of the antifouling paint via underwater brushing and exposing a new layer of antifoulant paint with ample supplies of toxicant to inhibit marine fouling.

It must be noted that the full Seamaster System is currently employed on only one vessel, the Norwegian Destroyer OSLO[34]. The system has yielded excellent results for the 3-1/2 years it has been in service[35]. Two reactivations have been performed on the coating since its initial application.

In addition to the complete Seamaster System, JOTUN offers a modified system which may be applied over a ship's existing anticorrosive coating providing the existing coating is in excellent condition. The effective service life of the modified system is two years. It is currently in use on 15 vessels[35].

A.4.1 STATE-OF-THE-ART (Cont'd)

ADVANTAGES OF SEAMASTER

- The system's four-five year service life offers extended intervals between drydockings.
- The system utilizes a form of copper as its toxic agent, as does the U. S. Navy's present hull coating system. Copper is mined domestically and is available at a relatively low price.
- The JOTUN Marine Coatings Company has 22 distributors in the U. S., located on all coasts.

DISADVANTAGES OF SEAMASTER

- Precisely controlled paint application is required for the Seamaster System to be effective. The manufacturer recommends that "plenty" of time be allowed for drying between coats and that the paint be given an opportunity to set thoroughly after the last coat of antifouling paint is applied - ideally for five days[33]!
- Because the product is only available from a single manufacturer, the use of competitive bidding in the procurement process would be precluded.
- The Seamaster System is applied to a substantially greater thickness than the Navy's present coating system, resulting in increased displacement of the vessel.
- The cost per gallon of the product is significantly higher than the cost per gallon of the Navy's present hull coating system[34].
- Besides being expensive and inconvenient, the coating reactivation process tends to increase the roughness of the coating system, and in some instances, when not properly carried out, may even result in damage to the anticorrosive coating.

A.4.2 TECHNOLOGY GAPS

A major factor affecting the service life of the Seamaster System is the quality of underwater brushing achieved during each reactivation period. At the present time, the most sophisticated method of reactivating an underwater hull coating is by use of the Butterworth SCAMP apparatus. Since underwater brushing equipment and techniques are addressed in detail in Appendix D, let it suffice to say here that the machine has certain limitations which restrict it from performing an effective brushing/reactivation of the entire underwater hull.

A.4.3 NEEDED RDT&E

RDT&E efforts are required to develop an automated underwater brushing apparatus capable of cleaning the entire submerged portion of the hull without damaging the coating system.

RDT&E efforts might also be devoted to determining a means of reducing the five-day curing time required after the application of the complete Seamaster System.

A.4.4 ENVIRONMENTAL CONSIDERATIONS

The Seamaster System employs cuprous oxide as its toxic agent. Since no regulations currently exist prohibiting the waterborne brushing of ships' hulls in navigable waters, the use of the Seamaster System poses no problems at the present time. Prior to adopting such a coating system, however, the Navy should consider the possibility that constraints might one day be placed on waterborne brushing operations, since the evolution results in spent antifouling paint being discharged into navigable waters. Having to drydock a vessel for the purpose of reactivating its long-life antifouling paint would certainly defeat the purpose of this type of coating system.

A.4.4 ENVIRONMENTAL CONSIDERATIONS (Cont'd)

FINDING: Though the Seamaster System appears to offer excellent anticorrosive/antifouling protection for extended periods of time, the System has not yet been fully tested.

RECOMMENDATION: Establish contact with the JOTUN Marine Coatings Company and the using commercial shipping lines to monitor the results of the service tests now in progress.

A.5 SELF-POLISHING COPOLYMER

A.5.1 STATE-OF-THE-ART

The Marine Coatings Division of the International Paint Company has recently introduced a three coat Self-Polishing Copolymer (SPC) Antifouling Paint System. The System provides antifouling protection only, and consequently, must be applied over an anticorrosive coating. According to the manufacturer, the System is designed not only to give extended freedom from fouling for two years or more, but also to contribute significantly to the reduction of hull surface roughness by its built-in self-polishing action[36].

Unlike other antifouling paints, the toxin in the SPC coating is chemically combined with the binder, so that leaching occurs only at the surface of the paint. As the surface wears away under water flow, new layers of toxin are exposed. The antifouling lifetime of the coating is, therefore, directly proportional to the film thickness of the applied coating.

A typical SPC application would consist of the following coats:

1st coat Red	3 mils
2nd coat Gray	4 mils
3rd coat White	4 mils

Unfortunately, SPC is not yet licensed for sale in the United States. The International Paint Company is planning to submit its registration application to EPA in September 1976[37].

ADVANTAGES OF THE SPC ANTIFOULING SYSTEM

- The SPC System not only prevents fouling but also reduces hull surface roughness, which is another factor that contributes to increased shaft horsepower requirements.

A.5.1 STATE-OF-THE-ART (Cont'd)

- The System requires no type of cleaning or reactivation during its service life.
- The SPC antifouling coating could be used in conjunction with the Navy's Formula 150 (series) anticorrosive coating which has already proven to be extremely effective.
- Since the SPC coating maintains itself in a highly polished state during its entire service life, no abrasive blasting is required prior to renewal of the coating.

DISADVANTAGES OF THE SELF-POLISHING COPOLYMER

- Though advertised to be two years or more, the service life of SPC has not been independently verified, at least to date, for a Navy application which requires the ship to spend a majority of time in port. Extended in-port periods might result in depletion of the antifouling toxicant at the surface of the paint since there is no water flow to wear away the depleted paint surface and expose new layers of toxin.
- SPC utilizes tributyltin oxide as its biocide, which has a relatively high level of human toxicity[6]. Tin, the raw material from which the biocide is produced, must be obtained from foreign sources.
- Procurement of the product for fleetwide use would require an exemption from ASPR since the product is manufactured by only one company on a proprietary basis.
- The product is not yet available for sale in the United States.
- Though the product may be applied to the hull appendages, it was not specifically designed for this type use and, consequently, will not perform as well in these applications[37].

A.5.2 TECHNOLOGY GAPS

The SPC formulation will not adhere properly to all types of anticorrosive undercoats. This has proven to be the case with the Navy's Formula 150 (series) anticorrosive coating. The use of a vinyl tar tie coat between the two coatings is scheduled to be tested on a submarine nose cone at Quincy, Massachusetts sometime in the near future[37].

A.5.3 NEEDED RDT&E

The service life of SPC is said to be directly proportional to the applied film thickness. Obviously, there are physical and practical limitations on the thickness to which the coating system can be applied. RDT&E efforts are needed to alter the SPC formulation so as to reduce the rate of wear on the coating, while at the same time, maintaining the system's superb antifouling properties.

A.5.4 ENVIRONMENTAL CONSIDERATIONS

The SPC coating employs tributyltin oxide (TBTO) as its toxic agent. Though highly effective as a marine biocide, TBTO offers the disadvantage of being toxic to humans as well. The use of the product, therefore, brings with it certain precautionary requirements during the application and removal of the paint system. Disposal of the wastes from these processes is also complicated due to the relatively high toxicity of the TBTO biocide.

A.6 GOODRICH "NO-FOUL"

A.6.1 STATE-OF-THE-ART

"No-Foul" is a proprietary product manufactured by the B. F. Goodrich Company, and the name itself is a registered trademark. It is an elastomeric sheet (80 mils thick) which is attached by a proprietary adhesive system to the underwater portion of steel, aluminum or wooden hulled vessels. The product may be applied to hull appendages (e.g. rudders, struts, sea chests, etc.) as well as to the hull proper[38]. On a test conducted by Battelle Columbus Laboratories and the U. S. Coast Guard, the "No-Foul" system received a rating of "outstanding" with a projected service life that was longer than any other system tested. The test results indicated that the Goodrich System offered a potential of up to ten years' resistance to corrosion and fouling[6]! Predominant use of "No-Foul" on U. S. Naval vessels is on sonar domes, although a few installations have been made to other appendages.

ADVANTAGES OF GOODRICH "NO-FOUL"

- The product offers a possibility of up to ten years' resistance to corrosion and fouling.

DISADVANTAGES OF GOODRICH "NO-FOUL"

- The initial cost of the material is relatively high.
- The Goodrich Company, which is the only source of the product, manufactures it on a proprietary basis.
- The application of "No-Foul" is a laborious process since the product is sold in rolls and must be measured, cut, and then attached to the hull by an adhesive.

A.6.1 STATE-OF-THE-ART (Cont'd)

- Relative humidity and temperature are critical factors in the application process. The temperature range for applying "No-Foul" is 50-90°F, with the relative humidity to be controlled within 5 units of the temperature[38].
- Problems have been experienced by the Navy in attaining good adhesion of the elastomeric sheet to sonar dome surfaces and in repairing damaged portions of the covering[13].
- Because of its low shear resistance, "No-Foul" is susceptible to damage by camels, balks, etc. if applied in the vicinity of the water line.
- "No-Foul" is difficult to remove from the substrate to which it was applied.

FINDING: Goodrich "No-Foul" has exhibited superlative anticorrosive/antifouling properties in panel tests[6] and in actual service use.

RECOMMENDATION: Continue to monitor the performance of "No-Foul" on Navy ships. Evaluate the effectiveness of the product on hull appendages (e.g. rudders, struts, roll stabilization fins, etc.) which are subjected to high velocity water flow, and also in seachests.

A.7 NAVY FORMULA 1020A

A.7.1 STATE-OF-THE-ART

Navy Formula 1020A, commonly referred to as "organotin paint", is a black antifouling coating which was developed by the Navy in the early 1970s. Its intended use is for boottopping on surface ships and for exterior topside surfaces on submarines where camouflage is desired. Trial applications of the product were made and evaluated on both surface ships and submarines. The results of these tests were somewhat spotty, with service lifetimes ranging from two to three years to only six or eight months[4]. Other problems were encountered with serviceability of the coating due to softening[39].

Unlike the Navy's current copper-based antifouling paints, Formula 1020A utilizes tributyltin oxide (TBTO) and tributyltin fluoride (TBTF) as its antifouling agents. Both of these substances are highly toxic to marine growth and relatively hazardous to humans. As a result of the latter, the observance of very rigorous and costly safety precautions during the application, removal and disposal processes has been required at Naval shipyards[11]. Some East Coast shipyards have refused to handle organotin paint operations within the constraints of current environmental protection regulations[39]. The Commander, Submarine Force Pacific Fleet, discontinued the use of Formula 1020A on Pacific Fleet submarines in July 1975 due to the softening problem, the environmental considerations, and the additional cost of compliance with the Navy's stringent safety regulations associated with applying and removing the product.

In view of the above, the Commander, Naval Sea Systems Command, restricted the use of organotin paints on all Navy submarines in November 1975[39]. Use of the product was limited to the following applications:

A.7.1 STATE-OF-THE-ART (Cont'd)

(a) maintenance of those portions of submarine hulls already painted with Formula 1020A.

(b) submarines in overhaul for which organotin paint had already been ordered.

Thus, Formula 1020A is in very limited use in the Fleet today.

ADVANTAGES OF FORMULA 1020A

- The paint appears to offer a longer service life than the Navy's current black antifouling coating (Formula 129/63)[46].
- Formula 1020A is compatible with the Navy's current Formula 150 (series) anticorrosive undercoating.
- The product can be used on aluminum as well as steel-hulled vessels.

DISADVANTAGES OF FORMULA 1020A

- Since the coating contains an organotin biocide, the rigorous and costly safety precautions prescribed in NAVSHIPS NOTICE 9190 of 28 May 74[11] must be observed during the application and removal processes.
- Disposal of the toxic waste materials generated from the application and removal processes is extremely costly.
- Tin, the metal from which the antifouling toxicant is produced, must be imported from foreign sources.
- Softening of the coating during its service life hampers serviceability (i.e., patch painting of damaged areas).

A.7.2 TECHNOLOGY GAPS

Technology gaps in this system and other coating systems containing organotin toxin lie in the area of worker and environmental protection during

A.7.2 TECHNOLOGY GAPS (Cont'd)

the application, removal, and waste disposal processes. Each of these topics is discussed in detail in Sections A.2.1.4 and A.2.1.5 of this Appendix.

A.7.3 NEEDED RDT&E

R&D efforts are currently under way at DTNSRDC, Annapolis to develop a means of detoxifying both the liquid and solid wastes generated during the application and removal of organotin coatings.

A.7.4 ENVIRONMENTAL CONSIDERATION

The environmental considerations associated with the use of coatings containing organotin toxins are discussed in Section A.2.1.4 of this Appendix.

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SHIP UNDERWATER MAINTENANCE, EVALUATION, & REPAIR
(SUMER)
MASTER PLAN

APPENDIX B

NON-COATING PROTECTIVE SYSTEMS

PREPARED FOR
NAVAL SEA SYSTEMS COMMAND

PREPARED BY:
Tracor Sciences & Systems

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APPENDIX B
NON-COATING PROTECTION SYSTEMS

B.1.0 INTRODUCTION

It has been conclusively proven that ship hull fouling and related corrosion and hull surface roughening dramatically increase fuel consumption and ship's power requirements, and also impose high hull maintenance costs. Signific nt additional fuel consumption is caused by reduced efficiency of seawater cooling systems due to fouling and corrosion. It has become increasingly difficult and complex to select cost-effective systems and equipment to control fouling and corrosion that also comply with environmental regulations and meet Navy operational needs.

Biological fouling and deterioration of materials used in marine service necessitate a high annual maintenance expenditure by the Navy, an expenditure of more than 215 million dollars in 1974.[1*] This is the direct cost attributable to biological deterioration of wood docks and piers and fouling growth on ship hulls only. Additional costs, both in dollars and in loss of operational capability, result from impaired performance and out-of-service time of ships, reduced service life, and loss of reliability in ocean surveillance equipment such as sonar sensors. These costs cannot be accurately determined but constitute a significant portion of the total cost of fouling and biodeterioration to the Navy. Data to support these statements were obtained from authorities from both the marine biological and marine engineering communities.

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*NOTE: References are listed in Section B.3.8.1 (page B-92).

B.1.0 INTRODUCTION (Cont'd)

The Navy annually prepares 10 million square feet of ship hull surface for antifoulant paints. The cost of labor and materials exclusive of drydocking costs is $15 million.[1] The largest number of active ships in the U.S. Fleet consists of submarines and destroyers. Experience has shown that these ships, because of service conditions, require the most frequent antifouling maintenance. Therefore, maintenance costs probably will not be greatly reduced unless significant improvements in hull protection are achieved.

Estimates of total Navy costs related directly to corrosion are difficult to identify. However, some appreciation for the magnitude of the costs can be obtained from a study performed on destroyers in 1961. It was concluded that a maintenance savings of $10,000 to $20,000[2] per destroyer could be realized through the limited use of sacrificial anodes. When this savings is multiplied by the fleet size of approximately 475 ships, it can be seen that the costs are substantial.

An integral part of the overall effort within the ship underwater body hull husbandry study is the performance of a study on non-coating protection systems. This study conducted by Tracor Incorporated will involve a review of the state-of-the-art of systems and concepts which will provide alternate methods of preventing fouling/corrosion of seawater systems and ship hull surfaces. The scope of the study will generally involve:

- Establishing the state-of-the-art concepts which can immediately be applied
- Consideration of the environmental impact of system concepts
- Identify necessary future RDT&E
- Recommend effectiveness evaluation and progress tracking plans

B.1.0 INTRODUCTION (Cont'd)

B.1.1 Problem Description

Existing underwater body surface protection systems such as anticorrosion and antifouling hull coatings are subject to in-service degradation and provide limited protection due to their inherent physical limitations and to a lesser extent due to coating loss caused by impact and erosion. Paint application techniques occasionally will result in voids or "holidays" which lead to accelerated corrosion. The physical limitations result in water absorption over a period of time due to porosity, and the development of blisters, cracks, etc., which reduce the effectiveness of the coatings. Consequently, it is necessary to have supplementary protective systems as a backup to the coating system.

The problem is to find anticorrosion/antifouling protection systems which will allow, in a cost-effective manner, at least 5-year drydocking intervals and provide effective corrosion and fouling protection throughout the life of the ship.

It is the purpose of this study to evaluate alternate or supplementary systems and concepts which, within the limitations of the applicable constraints, provide cost-effective anticorrosion and antifouling protection to Navy vessel surfaces.

B.1.1.1 Background. This discussion relates to the basic causes of underwater hull and seawater system deterioration corrosion and fouling.

Corrosion. Corrosion of metals is an electrochemical process similar to the operation of a wet cell battery. For ships the electrolyte is seawater; the anode is the hull and the cathode may be the propellers or hull appendages of more noble metal than the hull. In the corrosion process an oxidation reaction occurs at the anode from which metal atoms are ionized and go into solution leaving behind electrons. At the same time a reduction reaction occurs at the cathode, which consumes electrons. This process is called cathodic depolarization. For example, hydrogen ions in solution are combined with electrons at

B.1.0 INTRODUCTION (Cont'd)

the cathode and then reduced to hydrogen gas. In brief, if no protective measures are taken, a current will flow from the anodic hull to the cathodic propeller and appendages with the hull gradually being consumed or corroded. In addition to macroscopic galvanic effects between the hull and propeller, there are galvanic effects between bare metal (at holidays) and copper in anti-fouling paints, a weld metal and base metal, and local anodic and cathodic sites due to different surface conditions on freely corroding steel.

Oxygen depolarization is often considered to be the dominant depolarization mechanism of cathodes in seawater. This occurs where a sufficient concentration of dissolved oxygen exists. This cathodic reaction is represented as:

$$O_2 + 2H_2O + 4e^- = 4\ OH^-$$

Protective measures are, of course, taken to prevent ship hull corrosion. One obvious solution is to insulate the hull from the electrolyte and cathode, so that no current can flow. The hull coatings are most frequently paints. In any event, no coating can be a perfect electrical insulator or can stay perfect over an extended period of time. Holidays in the paint allow severe corrosion to occur at the metal surface. This will occur due to an increase in localized current density caused by a high cathode to anode ratio in a galvanic couple. The small anode (the holiday) is coupled through the hull to a large cathode, i.e., the cuprous oxide base antifouling paint, or propeller.

In the past, for displacement ships fabricated of steel and designed to operate at speeds below twenty knots, the supplemental protection has been provided by installing sacrificial anodes of zinc, aluminum, or magnesium on the hull. In essence, the hull becomes noble with respect to the sacrificial anodes, thus, being transformed to a cathode.

B.1.0 INTRODUCTION (Cont'd)

The back-up system was naturally called the cathodic protection system. Since 1966, impressed current cathodic protection systems have been increasingly installed on U.S. Navy ships. Most U.S. Navy ships have been designed and many others have been backfitted with impressed current cathodic protection systems. In this active system a current is impressed into the seawater to counteract the current that would normally flow from an anodic hull to the cathodic appendages. Consequently, the net galvanic (corrosion) current is zero or very small. In comparison to the sacrificial anode system, the impressed current system has the advantages of less weight, less speed loss and noise due to anode projection on the underwater hull, control of the protective current, and the ability to protect the hull from stray currents (e.g., during welding when grounds are improper). Extended drydock cycles and less expense over a service period greater than ten years[1] are thus possible.

Ship seawater system components such as oil coolers, main condensers, pumps, fire main, and other such components experience failures due to corrosion. This type of corrosion damage is attributed to turbulent aerated high velocity seawater. Dissimilar metals throughout the seawater systems also contribute to the corrosion problem.

Fouling. Surfaces continually exposed to seawater soon become covered with animal and plant organisms called fouling. Fouling is important to engineers concerned with the oceans because of its effect on ships, buoys, and marine structures. It increases hydrodynamic drag, clogs pipes, increases the weight of bodies, and may lead to increased corrosion of metals. In addition to fouling organisms, there are boring organisms that penetrate some materials and can cause structural failure because they remove material.[3]

Many species of animals and plants take part in fouling. Primarily they are the attached, or sessile, forms which inhabit the shallow water along the coast; however, many mobile animals are found among the sessile forms. Nearly 2000 species of animals and plants have been reported to make up fouling on man-made structures. Among these are over 600 kinds of plants and over 1,300 varieties of animals. The most commonly occurring fouling forms are Pelecypod Molluscs, (primarily mussels and oysters), Bryozoa, acorn barnacles, goose barnacles, green algae, Tunicates and Hydroids. Some other sessile groups such as Sponges and Corals are seldom observed.

The ensemble of organisms found on a submerged surface depends upon many factors, among the most important being the speed of water relative to the body, the season of the year, the geographic location, the depth, the texture of the surface, and the effects of light and gravity. Because some fouling organisms are unable to attach or are torn loose by the water's motion relative to the body, the number of species of fouling organisms found on ships is generally much fewer than that found on buoys or fixed structures. Barnacles are the only group which occur nearly as frequently on ships as on other structures. This is accounted for by the rapidity with which barnacles can grow and the firmness of their attachment.

In regions where there is a marked seasonal change in the factors controlling the growth of fouling organisms, such as the water's temperature, salinity, nutrient level, and oxygen concentration, there will be seasonal variations in the abundance of most fouling organisms. However, in tropical regions where the changes in conditions are much less pronounced, there may be no appreciable change in their abundance throughout the year. In addition to the known seasonal variations in abundance, there are often large, unexplained variations in abundance of a given organism from year to year. The variation in abundance of fouling organisms with seasons and for other reasons is cause for concern when testing the effectiveness of antifouling measures. This is because tests run to determine that the effectiveness of these measures may indicate that they are effective, when they may merely have been run at a time when the fouling organisms were not abundant. Generally, it is best to run tests of antifouling measures in tropical regions where seasonal variations are a minimum and reproduction and growth is likely to take place all year long. In any event, fouling tests should be conducted in consultation with marine biologists who are familiar with local marine fouling species.

The amount of fouling accumulated on ships depends upon the length of time that they spend in port, together with the location of the port. Ships which spend little time in port tend to be less fouled than those which spend long periods of time at rest in port. Most ships that have been at sea less than 30 percent of the time are found to be heavily fouled while very few of those that have been at sea more than 90 percent of the time become badly fouled.[3] Generally, fouling of ships is worst in tropical waters, where growth of organisms is rapid and there are no significant seasonal variations. Heavy fouling may occur in the summer in temperate climates, but little fouling generally occurs during the cold winter months. Ships which use freshwater ports have a significant advantage over those which use saltwater ports because there are very few freshwater fouling organisms. Those freshwater fouling organisms that do exist are mostly plants which grow near the water line.

As might be suspected, the reason for ships which cruise actively being less fouled than those which spend much time in port is the speed of the water relative to a moving ship. The movement tends to prevent the attachment of fouling organisms and shears off many that do attach. Barnacles are able to attach themselves to glass surfaces in currents up to 0.5 knots and tube worms are able to attach to glass surfaces in currents up to 1 knot.[3]

The most important effect of fouling on ships is an increase in drag due to an increase of surface roughness.

B.1.0 INTRODUCTION (Cont'd)

Not only are the hulls of ships subjected to fouling, but also are the propellers. The decrease in propeller efficiency due to fouling can be quite astonishing. Speed trial tests have shown that a substantial increased fuel consumption caused by fouling was due to its effect on the propellers. Even propellers in moderately good condition lose about 10 percent of the power available with new, well finished bronze propellers.

An additional important problem brought about by fouling organisms is the clogging of the interior of pipes and conduits. Fouling in pipes is most prevalent when the temperature is between 70^{o}F and 100^{o}F. It disappears when the water temperature is maintained at 100^{o}F and becomes much less when the temperature is kept below 60^{o}F. Pipes having a constant flow of sufficiently high velocity will usually not become fouled, while those having little flow or flow which stops for short periods of time generally become badly fouled.

Fouling organisms often cause corrosion of metals to which they are attached. Materials which have a low tolerance for crevice corrosion such as stainless steels may pit extensively under marine organisms. The worst offenders in this respect are barnacles and bryozoa. Fouling organisms may also injure paint meant to protect structures from corrosion and thereby cause extensive pitting. Sulfate-reducing bacteria, which are abundant in seawater and the mud bottom, are a cause of corrosion of iron and some newer copper alloys. They cause corrosion by bringing about depolarization of the metals surface as a result of their metabolic processes.

B.1.1.2 Constraints. The only significant non-technical constraints affecting the solution to the problem are those related to environmental contamination.

B.1.0 INTRODUCTION (Cont'd)

Environmental Considerations

The Department of the Navy has established a philosophy of protection of the environment and conservation of natural resources in compliance with all pertinent Federal regulations. Accordingly, the Secretary of the Navy stated in SECNAVINST 6240.6D that "the Chief of Naval Operations shall promulgate implementing directives and initiate necessary action to comply with the instructions of the Secretary of Defense."

OPNAVINST 6240.6D issued by the Office of the Chief of Naval Operations is applicable to all Navy commands, ashore and afloat. The policies, procedures, and actions prescribed therein are published without the necessity for implementing instructions from the various commands, bureaus, and offices, except as specifically directed therein. However, orginzations having significant environmental responsibilities may find it necessary to provide additional guidance and supplemental instructions.

Pertinent commands within the Navy are required by OPNAVINST 6240.3D (See Annex B-I) to initiate aggressive action to enhance the quality of the environment and combat environmental pollution, in accordance with the responsibilities specified therein, and provide the necessary direction to ensure that the provisions of OPNAVINST 6240.3D are adhered to on a continuous basis.

All facilities owned by, or leased to, the Federal Government must be designed, operated, maintained, and monitored to conform to applicable air, water, and noise standards established by Federal, state, and local authorities. However, it is not required that Naval facilities comply with state or local administrative procedures with respect to pollution abatement and control. By U.S. Supreme Court ruling on 7 June 1976, Federal facilities are not subject to state air pollution control permit programs or state issued Pollutant Discharge Elimination Systems permits.[4]

B.1.0 INTRODUCTION (Cont'd)

It is essential that an environmental impact assessment be made of an action which is judged to have a potential significant environmental impact, or is likely to be highly controversial with respect to environmental effects. An initial and continuing evaluation of the impact of an action on the environment, using established procedures, should be prepared. For actions which obviously have no significant environmental impact or are not highly controversial with respect to environmental effects, a written and dated memorandum to file should be prepared but the assessment need not be forwarded. The detail included is to be consistent with the scope of the endeavor addressed.

If the action is adjudged to have significant environmental impact, a Candidate Environmental Impact Statement must be prepared and forwarded to the Chief of Naval Operations (OP-45) for review. (For subsequent review and action requirements see OPNAVINST 6240.3D.)

With respect to anticorrosion and antifouling systems, the areas of environmental concern are limited to liquids, solids, or gases which would be discharged into the atmosphere or into navigable waters.

Hazardous substances are defined in the Federal Register, Volume 40, No. 250, Part IV, dated 30 December 1975. Part IV, entitled "Hazardous Substances," defines the characteristics, designation, removability, harmful quantities, and penalty rates. Part IV is expected to become law at the end of the third quarter of 1976.[5] It is also expected to become a section within the Federal Water Pollution Control Act at that time.[5]

Enforcement and enforceability of the Act regulating harmful quantities placed into navigable waters, etc., depends on the various hazardous substances selection criteria. To demonstrate the interrelation of the selection criteria, pertinent excerpts from Part IV (Hazardous Substances) are presented as Annex B-II to this Appendix.

B.1.0 INTRODUCTION (Cont'd)

As mentioned previously the anticorrosion and antifouling systems discharge liquids, solids, or gases into navigable waters or the atmosphere. Listed substances are designated as hazardous on the basis of toxicological properties of one component ion or group. As an example of a potential hazardous compound determination, chlorine dissociation from seawater may be challenged by the EPA. The Navy impressed current cathode protection system develops chlorine as a primary anodic reaction at the platinum clad anodes in seawater. The Navy is also currently considering the application of electrolytic hypochlorinator units, of the Engelhard design, to the ships' internal seawater systems. The amount of effective chlorine generation to control fouling without adverse effect on the internal surfaces of the seawater systems will have to be determined during evaluation testing. Also under consideration, with ultimate application to Navy ships, is the evaluation of a system which will discharge a chlorine compound out of the Perry Masker holes around the periphery of the ship's hull to reduce fouling on the ship's hull.

It is conceivable that under given Navy use conditions, assuming that either the seawater or hull, or both fouling control systems are installed and operational, in addition to the impressed current cathodic protection system, that an EPA challenge of chlorine discharge may be made. Of course, the contention can be made that the amount of chlorine in the water has not changed, since the chlorine present has been dissociated from existing seawater. In the event that an EPA challenge is made, a determination of the applicability of the toxicological criteria, removability, and harmful quantities will have to be made. The problem that the toxicological criteria determination raises is that the EPA has developed a tentative selection criteria which is based upon the effect the element or compound has on aquatic animals over a period of time. This does not consider the source of the compound but rather the fact that the element or compound is present.

B.1.0 INTRODUCTION (Cont'd)

The materials discharged by state-of-the-art systems and developing system concepts will be discussed under "Environmental Considerations" in the Discussion Section of this report.

B.2.0 FINDINGS AND RECOMMENDATIONS

The following findings and recommendations are based upon an evaluation of the state of development and suitability of a number of system concepts to fulfill Navy operational requirements. The limitations of applicable constraints and the cost effectiveness of the anti-corrosion and antifouling systems discussed are also considered.

B.2.1 Findings

The state-of-the-art systems that have reached a level of full operational readiness, having all required research completed, development models built and tested, and engineering and production models developed and evaluated, are relatively few in number. The impressed current cathodic protection system and galvanic anode installations for corrosion protection are considered to be fully operationally ready for fleet use. A seawater antifouling system known as the Engelhard electrolytic hypochlorinator has been used on commercial ships successfully, but is considered to be in an "evaluation" status from a Navy viewpoint. This system has not been fully evaluated for Navy use, but operational readiness will be determined only after shipboard tests have been completed. No other non-coating supplementary antifouling systems are known to be used as operational systems by the Navy.

Installation of impressed current cathodic protection systems is planned aboard 637 Class submarines for evaluation. The anodes on these boats have been mounted on the exterior of ballast tanks where it is not necessary to meet submarine SUBSAFE requirements.

The Navy impressed current cathodic protection system, the galvanic anode installations, and the Engelhard electrolytic hypochlorinator fouling protection system are undoubtedly the only supplementary systems which approach operational readiness. The Engelhard electrolytic hypochlorinator has been designed and produced and may be installed on

B.2.1 Findings (Cont'd)

board an FF-1052 class ship for evaluation. Operational readiness of this type of system will have to be determined after operational tests have been completed.

The remaining antifouling and anticorrosion systems discussed are in various stages of development.

B.2.1.1 Corrosion Protection Systems. In the following paragraphs corrosion protection systems, including current state-of-the-art and potential future systems, will be discussed.

B.2.1.1.1 Impressed Current Cathodic Protection (ICCP) of Steel Hulled Ships.

Summary: The Navy impressed current cathodic protection systems have been providing excellent corrosion protection on Navy Fleet ships. Operational anomalies (such as anode output current ripple) have delayed general use of these systems on submarines.[6]

In the time frame prior to the Korean War, ships were protected primarily with hull paint coatings. The paint coatings were gradually supplemented with galvanic anodes (zincs) due to the maintenance savings which could be expected from the cathode protection offered. A 1961 detailed study showed that a savings of \$10,000 to \$20,000[2] per destroyer per overhaul could be expected from a limited use of zinc anodes. The disadvantages of sacrificial anodes began to become apparent as the advantages of impressed current systems began to be recognized. While the impressed current system is initially more costly to produce and install and may require some maintenance during its life, it is flexible, light weight and automatically variable in current output to react to varying conditions of speed, salinity, temperature, and increased bare metal exposure. Figure B-1 shows cost comparisons with and without cathodic protection based upon estimated values for destroyers. The values used were corrected to 1971 dollars.

B.2.1 Findings (Cont'd)

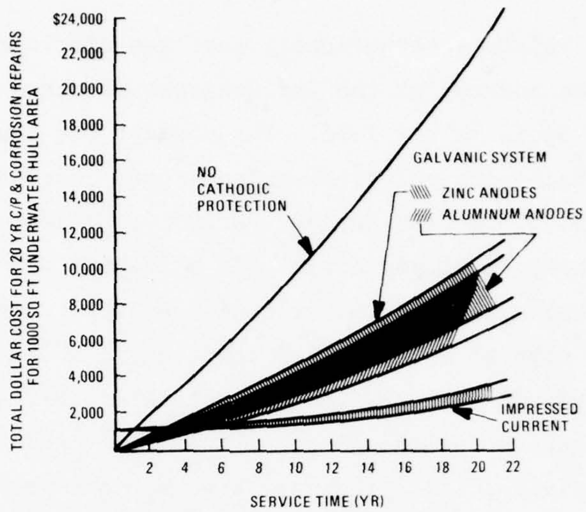

Figure B-1. Dollar Costs for 20 Years C/P and Corrosion Repairs[2]

The impressed current system has been extremely effective and is considered to be the lowest cost option for cathodic protection.

The Navy impressed current cathodic protection system is installed on approximately 1/3 of the U.S. Navy surface ships. A SHIPALT exists for most surface ships currently in the active fleet and is scheduled for accomplishment during upcoming regular shipyard overhauls. No operational fleet submarines are protected by this system at this time, but plans are being prepared for evaluation of systems on two SSN-637 Class submarines.

Major commercial manufacturers of impressed current cathodic protection systems are Engelhard Industrial, Union, New Jersey; Wilson, Walton International, Inc., Hoboken, New Jersey; Norton Corrosion Limited, Inc., Woodinville, Washington; Lockheed Marine, Ontario, California; and Morgan Berkley & Co. Ltd., Winchester, Hants, England. All of these companies provide impressed current cathodic protection systems for shipboard application to a worldwide market.

B.2.1 Findings (Cont'd)

Wilson, Walton International, Inc. has disclosed their development of a new anode concept at the 2nd Congress of Corrosion and Protection at Zaragosa, Spain in May 1976. The concept was developed to overcome some of the technological problems and costs associated with the manufacturing of platinum clad anodes. Briefly, their concept, identified as DSA (Dimensionally Stablized Anode), is a combination of the oxides of titanium and ruthenium applied to a titanium substrate and baked for a precise period of time at a controlled temperature above 700°C. The resulting solid solution is completely crystalline, hard and having an extremely rough surface. Although these films have relatively poor electrical conductivity, it is the very high surface area which overcomes the resistance problems and greatly enhances its electrochemical activity. The further development of these anodes and the operational evaluation should be monitored for applicability in corrosion protection systems. The Wilson Walton impressed current cathodic protection system also has a designed-in feature which prevents the possibility of overprotection of the ship hull in the event of reference cell failure. The relative merits of this feature would have to be the subject of a separate study.

The technological gaps that exist relate to the use of this type of system on submarine hulls. Pressure hull stuffing glands which are SUBSAFE or non-pressure hull fittings need to be developed for anode mounting. Knowledge is also very limited regarding the potential hydrogen embrittlement (stress corrosion) of high strength steels, i.e., HY-130, caused by hydrogen evolution at the system cathodes. Gaps also exist in knowledge regarding the impact of impressed current ripple on the fire control and sonar systems. Another unknown is the submarine electromagnetic signature potential (Underwater Electric Field Potentials) caused by the above mentioned current flow ripple. Current ripple is of 30 millivolts magnitude with passive filter installed in the system.

B.2.1 Findings (Cont'd)

The quantities of chlorine/sodium hypochlorite, or hydrochlorous acid developed at the anodes can be calculated. It is known that these compounds can form at the anodes due to their interactions with the seawater. The environmental concern for the compounds generated as free elements in the water is at present in a condition of benign neglect by the EPA.

The personnel requirement to operate and maintain the system equipment is normally limited to two people, one to energize (e.g., watch stander) and monitor system operation, and one to perform infrequent maintenance operations (technician). One person can and often does operate and maintain this type system.

Equipment support required consists of a volt-ohm meter and hardware related small tools.

B.2.1.1.2 Impressed Current Cathodic Protection of Aluminum Hulled Ships.

Summary: The more sensitive impressed current cathodic protection requirements of aluminum hulled ships create a number of inherent application problems.

The use of impressed current and sacrificial anodes on weight critical craft such as hydrofoils and surface effect ships, which are constructed of aluminum alloys, and a number of high strength steel components involves a number of inherent application problems. Anode positioning becomes difficult due to the relative locations of high strength steel and 5456, 5083, or 5086 aluminum components. Aluminum hulls can be driven highly cathodic when high current densities are required to polarize the cathodic materials (high strength alloys) to the corrosion potential of the aluminum.[7] Under these conditions, an alkaline condition is developed at the metal surface. The steel and aluminum is protected by mild alkaline conditions; aluminum, however, is amphoteric and will deteriorate in strong alkaline solutions. Driving

B.2.1 Findings (Cont'd)

aluminum excessively cathodic, with resultant rapid deterioration, is called over-protection. Breaks in the shields between the anodes and the hulls could lead to high current densities which likewise results in over-protection.

Separate active (impressed-current) and passive (sacrificial anode) systems have previously been investigated to provide cathodic protection. Studies of passive systems have indicated that they impose weight, drag, and maintenance penalties which are greater than those resulting from the active system. Therefore, active system concepts currently are being concentrated on.[7] No practical experience has been gained to date on such systems where aluminum hulls are subjected to high operating velocities; however, a considerable number of laboratory experiments have been performed by Bell Aerospace Company to evaluate corrosion of dissimilar metals at speeds up to 90 knots.

The environmental and personnel considerations and the equipment support requirements are identical to those required for protection of steel hulled ships.

B.2.1.1.3 Impressed Current Cathodic Protection of Seawater Piping Systems.

Summary: Impressed current cathodic systems for seawater system corrosion protection appears to be in the engineering development stage.

Cathodic protection levels established within these systems have been satisfactory. However, much knowledge relative to the proper anode placement with relation to water velocity to establish the lengths of protection along the system, appears to require further development.

The environmental and personnel considerations and the equipment support requirements are identical to those required for protection of steel hulled ships.

B.2.1 Findings (Cont'd)

B.2.1.1.4 Cathodic Protection Using Pulsed Direct Current Systems.

Summary: Pulsed D.C. cathodic protection systems, which are in the research stage, appear to offer power saving advantages.

Pulsed impressed direct current cathodic protection systems are under development by Shell Development Division in Houston, Texas. These systems, in the research stage, have demonstrated some beneficial characteristics, as compared to non-pulsed systems. The electronic controls reportedly modulate the current outputs better than state-of-the-art non-pulsed systems; i.e., radio frequency interference (RFI) is not experienced in the anode current output although a 20-volt pulse level is prohibitive currently. The system has a very low percentage of ripple on the output current.[8] This type of system also reportedly results in less power loss to capacitive energy while maintaining the required surface polarity. Although this type of system has been evaluated primarily on off-shore platforms, a ship installation version of this system has been designed.

It is anticipated that the environmental and personnel considerations and equipment support requirements will be the same as those required for protection of steel hulled ships.

B.2.1.1.5 Ship Hull Corrosion and Fouling Prevention Using Copper-Nickel Clad Materials

Summary: Copper-nickel clad hull structural plate material development, offering apparent substantial corrosion and fouling savings, is in the hull fabrication state of development. Roll-bond clad hull plates demonstrate good weldability. At-sea operational tests will be performed after completion of prototype construction.

The International Nickel Company, Copper Development Association, E.I. DuPont, and Lukens Steel Company have been jointly developing

B.2.1 Findings (Cont'd)

copper-nickel clad steel plate for ship hull construction.[9] Preliminary tests involving use of a 5/16" thick 90-10 copper-nickel material on a 67 foot shrimp boat hull, the Copper Mariner, were very encouraging. The performance of the copper-nickel hull over two and one-half years of operations showed significant savings as compared to a steel hulled sister ship. The factors contributing to the savings were: (1) reduced fuel bills, (2) higher speeds, (3) no corrosive deterioration of the hull material, (4) no expenses for periodic haulout, scraping, and painting of the hull, and (5) more time at sea.

Representative percentage improvements were:

- Speed Improvement - 15 percent[10]
- Fuel Consumption Decrease by 15 percent[10]

The techniques for developing the copper-nickel clad by E.I. DuPont and Lukens Steel Company are explosive bonding (known as Deter-clad) and roll bonding, respectively. Both of these techniques result in an electron-sharing bond of the copper-nickel with the substrate steel plate.

The process currently used for manufacturing clad steel plates suitable for use as ship hull plates is hot roll bonding of a "pack."[10] This pack is assembled with two interlayers of copper-nickel plate, separated by a parting compound, which are placed between two steel slabs and the edges welded together. Thus, the rolling is done on two steel faces and the bonding occurs during rolling.

Lukens Steel Company recently supplied 22 Alloy 706 clad plates (90-10 copper-nickel-clad on ABS structural backing steel) for fabrication of the hull of a commercial fishing boat.[11] The Copper Development Association, Inc., sponsor of the clad hull project, will closely monitor both the construction and the service performance of the boat.

The technological gaps that exist relate primarily to manufacturing techniques for applying a copper-nickel surface to a steel plate substrate and its corresponding cost. The process giving the greatest bond strength is explosive bonding. However, the hot rolling of such a composite is not an established commercial process. Although not yet developed as a process, the preparation of a composite slab by either casting or diffusion bonding would be expected to yield a clad plate that is less expensive than a corresponding plate produced by hot ro'l bonding from a pack.[12]

Welding techniques offer a method of applying a copper-nickel surface to a steel plate. A solid clad may be obtained by use of a plasma-arc hot wire process. This process uses a copper-nickel wire and deposits it through use of resistance heating and a plasma torch. A hull plate cost which is nearly 50 percent of the cost produced by roll bonding could be achieved with a loose cladding process in which copper-nickel plate is spot welded to a thick steel plate.[12] The welding technology is well established, but the suitability of this type of caidding construction to ship hull applications has not been established.

Adhesive techniques are another alternative method of cladding, though no reliable data is available on service in the marine environment.

B.2.1.1.6 Galvanic Anode Hull Protection.

Summary: Zinc anode materials are used on submarine and surface ship hulls for corrosion protection. They are gradually being replaced by impressed current systems on surface ship hulls. Development efforts required include the preparation of specifications for aluminum anodes and the development of environmentally acceptable anode materials.

Galvanic anodes, primarily zinc types, are still in use on some Navy ships and foreign ships for hull protection. This represents

B.2.1 Findings (Cont'd)

the 1960's state-of-the-art. Zinc anodes are concentrated in the stern area of the ship in order to better protect propeller and dissimilar metals. It is noteworthy that galvanic anodes provide very little cathodic protection when the ship is underway.

Light metal aluminum and magnesium anodes receive very little use due to lack of manufacturing specifications in the case of aluminum, and to the potential safety hazards associated with the use of these light metal alloys.

Reported safety hazards relate to potential ignition of volatile vapors in ship cargo spaces caused by sparks from anodes if accidentally dropped. Coast Guard regulations limit the use of aluminum anodes to specific heights in the cargo spaces and prohibit magnesium anodes in cargo spaces for this reason.

Relative costs for installing and maintaining a galvanic (sacrificial) cathodic protection system are illustrated in Figure B-2 using initial installation costs for an automatically controlled C/P impressed current system as a base (1.0). Although initial installation costs of the sacrificial system is considerably lower, the cost advantage of the impressed current system begins after 7 to 10 years of service.[2]

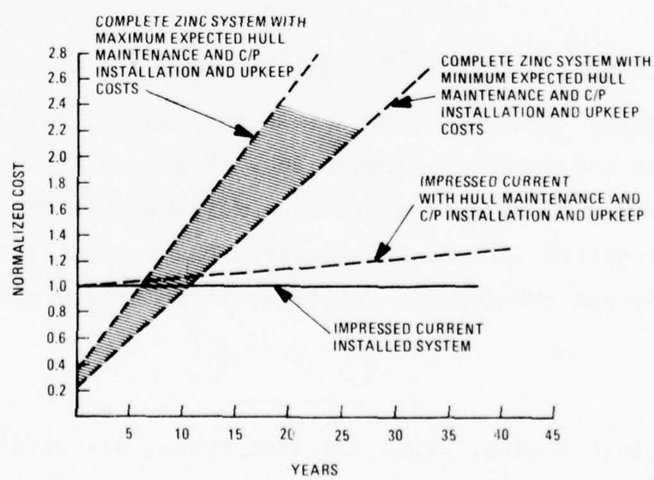

Figure B-2. Relative Costs for Installing and Maintaining Galvanic Anodes[2]

B.2.1 Findings (Cont'd)

The technological gap that exists is the lack of identification of environmentally acceptable anode compositions which do not contain the toxic material "cadmium" and toxic compound forming material "mercury."[13]

The environmental concern is, of course, that zinc anodes, which are the primary anode material in use today, contain cadmium, and the aluminum anodes contain mercury. Fortunately, at present there are no known cases of EPA serious concern about the introduction of these toxic compounds into navigable waters.

There are no training and manning requirements for operation and maintenance since, after installation, galvanic anodes perform cathodic protection through the process of galvanic anode material dissipation. They are replaced during periodic maintenance availabilities. It should be noted that, technically, galvanic anodes do not do the same job as impressed current systems.

Support equipment consists of replacement anodes.

B.2.1.1.7 Stray Current Corrosion of Steel.

Summary: Corrosion, believed to be due to stray current, has been of concern to the Navy over the past few years. Several incidences of severe corrosion on Navy ship hulls have occurred recently.[14]

Accelerated corrosion on Navy ship hulls has occurred recently. The source of the currents causing the corrosion has not been locatable in many instances. Field studies have been made where the recorded hull potentials showed large fluctuations in the positive direction which indicated that stray currents did exist at some Naval berthing sites.[14] A study by NSRDC[15] reported in June 1975 that no significant stray current sources could be located at State Pier, New London. To gain greater insight into stray current corrosion and mitigation, the Naval Research Laboratory (NRL) has performed laboratory experiments to quantify the amounts of corrosion caused by stray currents.

B.2.1 Findings (Cont'd)

Mr. T.J. Lennox, Jr. and Mr. M.H. Peterson of the Naval Research Laboratory (NRL) conducted experimental studies of stray current corrosion of steel. The tests utilized two carbon steels in stray direct current fields of two intensities. These studies were conducted on laboratory scale models in order to minimize the variables inherent with field studies. In all experiments, a solution simulating seawater was used. The practical effect on the test specimens which is indicative of ship corrosion follow.

The metal-loss rate was essentially reduced to zero when the current density on either a steel cathode or a bipolar cathode was 10 mA/sq. ft. or greater. This indicated that, essentially, complete cathodic protection was obtained at these current density levels. At the anodes and bipolar anodes, current densities of 5 and 10 mA/sq. ft. caused general corrosion over the entire exposed area.

Another type of corrosion could be caused by improper grounding of a welding power source (on a ship other than the ship being welded). This type of corrosion has been identified as "imposed voltage"[15] corrosion. A number of people in the corrosion field consider this to be a specialized case of stray current corrosion. Submarine A in Figure B-3 would suffer imposed voltage corrosion over the entire hull due to the imposed voltage source. Submarine B in Figure B-3 would suffer accelerated stray current corrosion predominantly on its starboard side, as an induced bipolar anode.

B.2.1.2 Fouling Protection Systems. The relative impacts that fouling and corrosion have on ship hull smoothness and fuel consumption are depicted in Figure B-4.[16] As can be seen, the hull roughening caused by corrosion is cumulative and occurs over a long period. Fouling, on the other hand, causes a non-cumulative roughening, from the standpoint

B.2.1 Findings (Cont'd)

that it can be completely removed during drydocking. However, the short term impact on speed loss of fouling is much more costly than that caused by corrosion. Therefore, the importance of fouling prevention systems should be obvious.

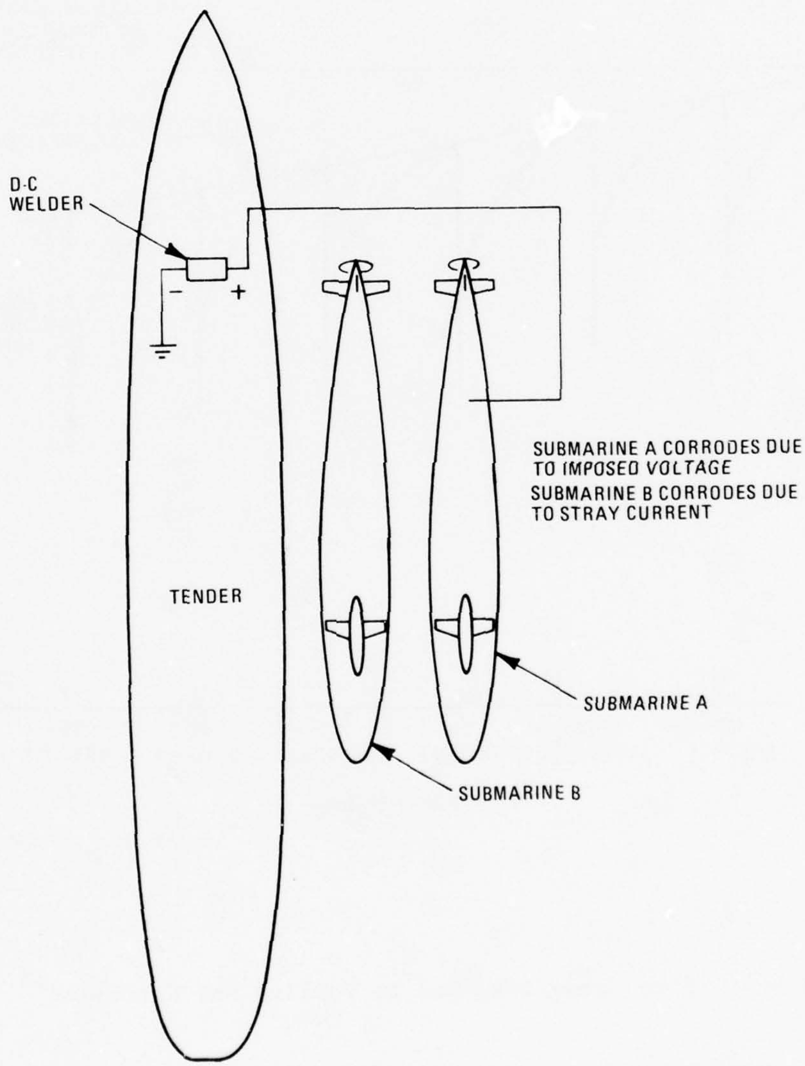

Figure B-3. Imposed Voltage Corrosion Situation[15]

B.2.1 Findings (Cont'd)

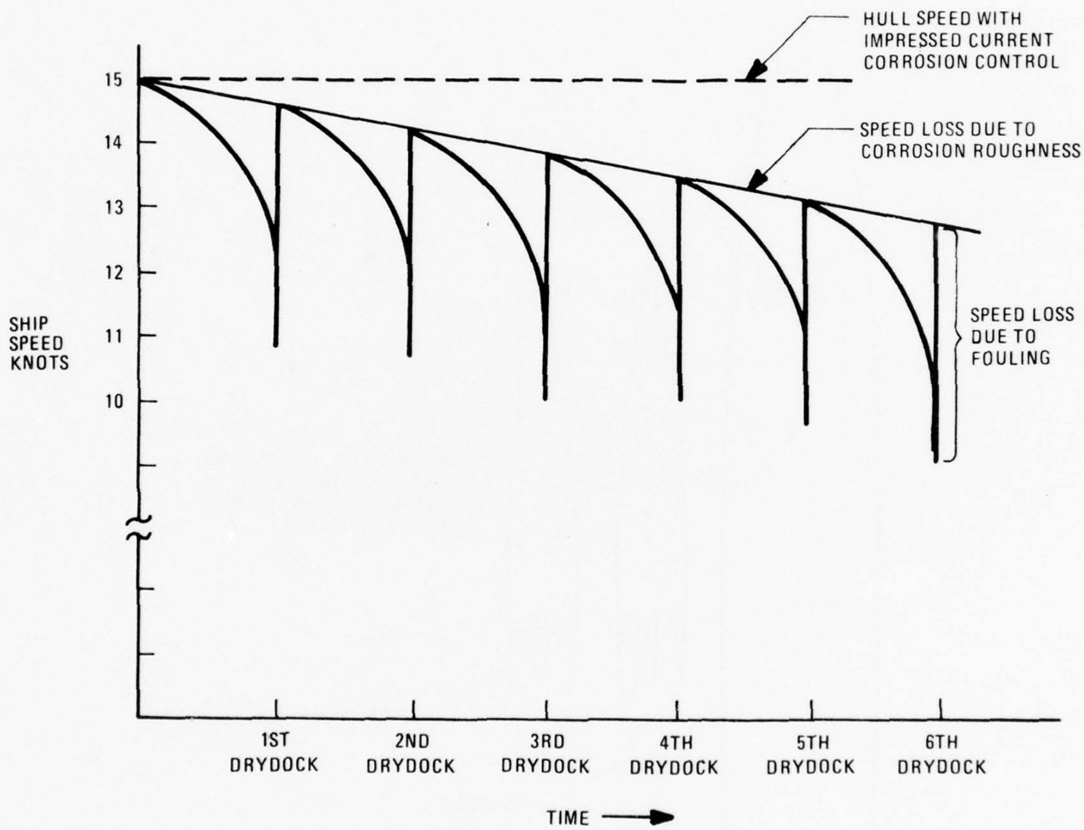

Figure B-4. Ship Speed Loss Due to Fouling and Corrosion[16]

B.2.1 Findings (Cont'd)

B.2.1.2.1 Bagging.

Summary: Bagging of propeller assemblies during inactive periods has not been found to be an effective means of preventing fouling, or reducing the current output requirements of impressed current cathodic protection systems.

A comprehensive search of the Naval and commercial experience with bagging identified that bagging of propellers had been tried on Navy Reserve Fleet ships at San Diego. No written accounts of the benefits of this technique to prevent fouling or corrosion could be found. However, personal association with the experimental technique revealed that the bagging had negligible effect on the amount of current required from an impressed current cathodic protection system to provide corrosion protection of the stern hull and propeller.[17] Experience has shown that, due to the marine fouling existent on the propellers when the bags are installed around the propellers, hydrogen sulfide and/or ammonia develops, which causes the bronze material in the propellers to pit and/or crack.

No continuing interest has been shown in the techniques at San Diego.

B.2.1.2.2 Sonar Dome Fouling Control.

Summary: A cell/injection system, using state-of-the-art components of a hypochlorination system, has been proposed to the Navy. This system has not as yet been installed for evaluation.

The state-of-the-art currently consists of a cell injection system developed by Engelhard Systems. This system uses an operational chlorine generator and a net to hold the sodium hydrochlorite near the dome. The net is installed by ships forces. No Navy evaluations have

B.2.1 Findings (Cont'd)

been made on this system, but the manufacturer has provided an unsolicited proposal for a Navy study.

B.2.1.2.3 Fouling Control Via Chlorine Distribution in Seawater Piping Systems.

Summary: Engelhard electrolytic hypochlorinator systems are in wide usage in landbased and shipborne installations. Operational characteristics onboard Naval vessels require evaluation.

Fouling control in U.S. Navy ships seawater piping systems has been largely a matter of designing the piping systems so as to provide for seawater velocities in excess of 3 ft./sec.[18] Electrolytic hypochlorinators are currently available and used in numerous landbased and commercial shipboard installations. This type of system prevents fouling in sea chests and seawater piping systems by injecting 0.5 parts per million (ppm) of sodium hypochlorite generated through electrolytic decomposition of seawater.

This type of system is currently used on one U.S. Military Sealift Command ship, the USNS WHEELING. It is also planned to evaluate a shipboard installation on an FF 1052 class ship. The system designs are simple and the hardware is relatively inexpensive. Effectiveness of the system in preventing marine fouling has been established by the British Ship Research Association[19] and numerous American Shipping Companies. This system is produced by Engelhard Systems.

Technological application characteristics of these systems would have to be resolved for Navy ship use in the following areas:

1. The effect of electrochemically generated chlorine on ships system
2. Determination of effective hypochlorite dissociation rates for Navy ship seawater systems

B.2.1 Findings (Cont'd)

3. The development of a sensor for monitoring effective chlorine and for providing automatic system control

The personnel required to operate and maintain the systems equipment is limited to two people, one to energize and monitor system operation, and one to perform infrequent maintenance operations.

Equipment support required consists of a volt-ohm meter and hardware related small tools.

The environmental problems associated with the use of this type of system will depend on the dissociation rates of chlorine from seawater found necessary to provide effective fouling control. The design goal for Navy application would be zero discharge of effective chlorine. The manufacturers literature notes that normal operation of the system results in a dissociation rate of 0.5 parts per million on a continuous basis. This rate of chlorine dissociation in navigable waters would be within the EPA requirements for hazardous substances.

B.2.1.2.4 Fouling Control Via "TOXION TWO" Distribution In Seawater Piping Systems.

Summary: The "TOXION TWO" system, using a tin-based antifoulant, is used successfully in European shipboard seawater systems. This system warrants U.S. evaluation for potential Navy use.

The "TOXION TWO" antifouling system is produced by F.A. Hughes and Company Limited in Epson, Surrey, England. The "TOXION TWO" antifoulant agent is a tin-based material, mixed with a water carrier fluid. Two stages of dilution occur in the distribution system, resulting in approximately 0.01 parts per million of toxin agent discharge into the seawater system.[20] It is reportedly used with excellent results, in all types of seawater cooling systems. The TOXION TWO system is used only on European vessels, primarily in England and the United Kingdom.

B.2.1 Findings (Cont'd)

These systems are far enough downstream for U.S. application that equipment support and technological gaps are not currently obvious. No environmental problems are caused by the TOXION TWO antifoulant, since it is an organic tin-based toxicant carried in a water solution and does not exceed the harmful quantities in the EPA Hazardous Substances Listing.

These systems are operated and maintained by two people from the ship's engineering staff.

B.2.1.2.5 Electrolyzed Seawater System.

Summary: An electrolyzed seawater system, developed in Japan, has effectively prevented fouling on a 50,000 DWT tanker and appears to be technically and economically feasible on a 250,000 DWT vessel. This system warrants U.S. evaluation for potential Navy use.

This system to prevent ship hull fouling was developed at the Nagasaki Shipyard in Japan by Mitsubishi Heavy Industries, Ltd. The system electrolytically develops chlorine from seawater and, after combining the chlorine laden seawater with pressurized air, delivers the mixture through nozzle pipes fitted to the bilge parts of the hull. The mixture rises up to the surface along the ship's side hull plates as a minute bubble screen type flow.

The antifouling effect of this system has been confirmed on a 50,000 ton ore carrier.[21] Design improvements on this system and analysis of the application to a 250,000 ton tanker show the system is practical and economically justifiable, based on a 3 year cost pay back test normally used in the shipping industry.

The current designs are estimated to have an 8 to 10 year service life with minimal maintenance requirements.

B.2.1 Findings (Cont'd)

Magnesium hydroxide separated from the seawater is collected in holding tanks and the hydrogen separated is passed through an anti-explosion filter and enters a ventilation fan duct, where it is diluted.

Large tankers and ore carriers, if docked at 12 month intervals, would, per the analysis, gain 0.5 and 1.0 knots in service speed due to electrolytic protection.[21]

These systems are far enough downstream for U.S. application that personnel, equipment support, and gaps in technology are not currently obvious.

The environmental problems associated with the use of this type of system will depend on the amount of chlorine or leached copper added to the water by the system.

B.2.1.2.6 CEPI-COMAV Magnetic Scale Prevention Device

Summary: The Belgium "CEPI-COMAV" magnetic scale prevention and removal units have been used successfully on European shipboard seawater systems to remove and prevent calcium carbonate scale deposits. In heating calcium bicarbonate, normally found in seawater, the calcium bicarbonate breaks down to the insoluble calcium carbonate. This normally crystalizes out of solution which forms a filter to trap algae and other marine fouling substances.

This type of device is used on over 100 Swedish and 1000 Russian seagoing vessels.[22] It operates by magnetically converting dissolved salts (principally calcium carbonate) from the calcite form to the aragonite form (a powdery substance which will not form scale as calcite does). The CEPI-COMAV unit requires no power input; it is designed for direct insertion in a piping system and maintenance is minimal. The ship degaussing effects on the magnetic characteristics of the magnets in the CEPI units are not known.

B.2.1 Findings (Cont'd)

These devices, developed and marketed by the S.A. Epuro Company in Antwerp, Belgium, are used in seawater systems containing evaporators, heat exchangers, air conditioners, etc. The magnetic influence, however, is destroyed in system components which have a high (>9,000 BTU's/sq. ft./hr.) heat transfer rate. Also, flow of water through pumping elements degrades the magnetic effect on the dissolved salts, such that location in the system of the device becomes important.

U.S. utilization of these devices is currently limited to universities and commercial applications, although a controlled test evaluation of these devices is planned to be performed by the Naval Academy at Annapolis, Maryland.

B.2.1.2.7 Ultrasonic Hull Vibrations Techniques of Preventing Fouling.

Summary: The Soviets use magnetostriction properties of hull transducers to obtain ultrasonic antifouling hull protection. Distribution of high frequency vibrations over hull structures requires evaluation.

The Soviets have done most of the work involving the use of ultrasonic vibrations to prevent hull fouling over the past 12 years. The Soviet maritime fleet now has about 20 vessels equipped with ultrasonic antifouling protection systems. Despite the fact that the latter have been in use for over 10 years, there are still no data on the distribution of high-frequency vibrations over hull structures.[23] The objective of their studies was to check the efficiency of ultrasonic antifouling protection and study of vibration damping in the hull by measuring high-frequency vibrations on a KRASNOGRAD-Class ship. The ultrasonic system on these ships incorporates a vacuum tube ultrasonic oscillator with a 200-w power output and four more oscillators. The oscillator's output voltage frequency varies within 17 to 30 kHz. The oscillator uses a self-excitation and frequency-modulation circuit.

B.2.1 Findings (Cont'd)

The magnetostriction oscillator consists of four nickel plates assembled in a package and soldered to a steel prism, which is welded to the the inner side of the hull plating. The plates carry a winding in which a variable magnetic field is produced. Under the effect of the magnetic field, the plate package, possessing a magnetostriction property, undergoes periodic changes in size. The vibrations of the package are transmitted through the prism (waveguide) to the outer hull plating.

B.2.1.2.8 Aquatron Scale and Algae Elimination System.

Summary: The American produced Aquatron system has the unique characteristics of preventing algae and calcium carbonate from forming in water handling systems. This fact should make these systems useful in preventing marine fouling from accumulating in shipborne seawater systems.

The Aquatron system, a product of Delta Tech Corporation, Dothan, Alabama, stops scale (deposits of calcium, magnesium, and other salts) formation, dissolves existing scale, and kills algae. The system stops the formation of scale in water lines, boilers, heat exchangers, and other equipment where water flows. The system works by electronically reversing the normal chemical process of scale deposition without temperature changes or chemical additions to the water.[24]

The system will dissolve salt scale already deposited on pipe walls or equipment surfaces. The electronically treated water dissolves existing scale deposits and will continue to dissolve deposits and prevent new scale from forming as long as the system operates. It works without chemicals, acids, or mechanical cleaning methods and can be installed in any type of equipment, no matter how thick deposits have become.

Algae causes blocked water flow, increased fuel costs, and reduces machine efficiency in air conditioners, cooling towers, and other

B.2.1 Findings (Cont'd)

mechanical shipboard equipment. The Aquatron system creates a water environment in which algae cannot live by applying an electric charge to the living micro-organism. This charge effectively destroys the plant and prevents new algae from growing.[24] It is anticipated that Aquatron can prevent slime film from forming which precedes attachment of other marine fouling organisms.

The Aquatron system has three major components: the energy cell, the ionization chamber, and the ionization electrode assembly. A safe, completely enclosed energy cell supplies the system with the proper ionization voltage, constantly regulated for maximum efficiency.

The ionization chamber, for instance, is installed in the feed-water line for treatment of all water entering a boiler system. A valved bypass line permits all normal water flow operations such as blowdown and effluent discharge. A set of insulated stainless steel electrodes is installed within the ionization chamber or area to deliver the proper electric field for scale and algae elimination.

The Aquatron system also lowers energy costs. A very thin (1/32 inch) coating of scale on a boiler tube will insulate the tube and reduce heat transfer from 20 to 25 percent. Similarly, a thick coating of algae on cooling surfaces and pipes will reduce water flow and cause pumps and fans to work under full or overload conditions. When scale and algae are eliminated, heat is transmitted more efficiently, water flow is increased, and equipment load factors are reduced.

The Aquatron system does not create pollution concerns. The use of expensive scale control chemicals, algae poisons, and other pollutants is normally eliminated. No adverse temperature or chemical changes occur in the treated water and no acids or cleaning chemicals need be used anywhere in the Aquatron protected equipment. The Aquatron system operates on low D.C. voltages within sealed, grounded enclosures and is completely safe for workers and maintenance personnel. The

B.2.1 Findings (Cont'd)
system meets or exceeds all applicable OSHA regulations for electrical equipment of this type.

B.2.2 Recommendations.

The current state-of-the-art, gaps in technology related to the concepts identified, the environmental considerations, the training/manning required, and the equipment support requirements have been described. The most effective techniques to meet Navy operational objectives that can be applied immediately or in the near future will be described. The research and development required to resolve existing technological problems and gaps and to provide for effective utilization of current and developing concepts will be identified. Effectiveness evaluation plans and development progress tracking techniques to achieve the development goals required will be discussed.

Summarizing the immediate applicability of the systems to be discussed in paragraph B.2.2.1 to Navy surface ships and submarines, the following recommendations are made:

1. That impressed current cathodic protection systems continue to be installed on surface ships as the most reliable, flexible, and cost-effective means of providing supplementary hull corrosion protection. It is further recommended that these protection systems be installed during the initial construction of ships rather than as a retrofit in the form of a SHIPALT.

2. That the category of SHIPALT's for installation of impressed current systems in amphibious ships be changed from "D" to "K," which would allow central funding rather than funding from the Type Commanders maintenance funds, which are always very limited. This would allow a higher priority to the SHIPALT accomplishment and provide more

B.2.2 Recommendations (Cont'd)

assurance of accomplishment at each ship's next scheduled regular shipyard overhaul (ROH).

3. That research funding be allocated and a program initiated for threat evaluation of underwater electric potential fields associated with impressed current cathodic protection systems on submarines. It is also recommended that a parallel effort be undertaken to develop controllers and power supplies suitable for SES application.

   A development program is also needed to develop and evaluate a SUBSAFE submarine hull penetration fitting for anode attachment in the pressurized hull area, and a non-pressure hull type alternate fitting.[25]

4. That research programs be initiated and funding allocated to support surface effect ships effective application of impressed current cathodic protection systems[26] in the following areas (see paragraph B.3.3.3 for additional details):

   - Remote Anode Studies
   - Effect of Protection Potentials on Titanium and 17-4PH Stainless
   - Hull Anode Design
   - Controller and Power Supply Design
   - Velocity Effects on Dielectric Shield Materials at High Velocity (50 to 100 Knots)
   - Pilot System Installation Evaluation

5. That an awareness be maintained of the progress of emerging technologies which represent potential advancements in the state-of-the-art of cathodic protection, such as pulsed D.C. current application.

B.2.2 Recommendations (Cont'd)

6. That the Navy, with industry support, continue to evaluate foreign technology in the areas of anticorrosion and antifouling systems. Antifouling systems which merit further immediate attention include the operational Japanese electrolyzed seawater system, the British TOXION TWO system, the Belgian CEPI/COMAV devices, and the American Aquatron system.

7. That the Navy develop prototype full ship hull chlorine antifouling system and conduct sea trials of the prototype system.

8. That Navy programs be continued in the area of stray current corrosion evaluation with emphasis on the location of sources.

9. That the Navy immediately fund additional development efforts to support current and future needs of galvanic anode technology, such as the development of specifications for aluminum anode composition and the development of environmentally acceptable anode materials.

10. That the Navy initiate and fund development programs to adapt existing shelf hardware to provide full hull fouling prevention to submarines and surface ships. Two such candidate systems are the electrolytic hypochlorinator and the electrolyzed seawater systems.

11. That evaluation of feedback type control system hardware for seawater system chlorination be funded.

12. Galvanic anodes provide adequate corrosion protection, for ship hulls while the ship is dockside. Impressed current cathodic protection systems provide adequate corrosion protection both during dockside periods and while underway,

B.2.2 Recommendations (Cont'd)

necessitating that the ICCP system be energized at all times that the ship is waterborne when this type of system is use exclusively. It has been recognized that existing training of the ships ICCP system operating personnel is less formalized and complete than thought desirable. More operational training is considered necessary. Therefore, it is recommended that a class "C" course be established on the east and west coasts. In lieu of a formalized ashore course, an onboard contractor training course may be far more cost-effective.

B.2.2.1 Applicability of State-of-the-Art Systems. The immediately applicable antifouling and anticorrosion systems described are those which would be supplementary to existing protective measures such as antifouling and anticorrosion paint coatings and velocity control (in excess of 3 ft/sec) in seawater systems. The physical geometric shape of surfaces, operational requirements of vessels, and the isolation of surfaces provide the basis for discussion of pertinent systems under the headings that follow.

B.2.2.1.1 External Ship Hulls and Domes.

- Corrosion protection of Navy steel and aluminum ship hulls and domes as well as propellers and appendages is presently being provided by impressed current cathodic protection systems and/or galvanic anodes. The use of galvanic anodes is gradually being phased out due to the greater flexibility, long life, and lack of environmental contamination problems associated with impressed current systems. The galvanic anodes also provide very little protection while the ship is underway.

  Impressed current cathodic protection is considered to be the lowest cost option available to the Navy. There are

B.2.2 Recommendations (Cont'd)

no alternate candidate systems which are close to an operational ready status. Shell Development Division in Houston, Texas is developing a pulsed direct current type of system. This appears to be the only candidate technological improvement in terms of lower power use of existing non-pulsed D.C. impressed current systems. It is currently in the laboratory development stage. This type of system supplies power to the anodes on an on/off basis which may create an Underwater Electric Potential (UEP) signature problem.

- Fouling protection of Navy ship hulls is currently provided by antifouling paints exclusively. The only alternate system identified is an electrolyzed seawater system developed at the Nagasaki Shipyard in Japan.

  The antifouling effect of this system has been confirmed on a 50,000 ton ore carrier. Design improvements on this system and analysis of the application of a 250,000 ton tanker show the system is practical and economically justifiable based on a 3 year cost pay back test normally used in the shipping industry.

  The current designs are estimated to have an 8 to 10 year service life with minimal maintenance requirements.

  The 90-10 copper-nickel clad materials currently under fabrication and operational tests may, also, become viable alternate protection techniques in the near future.

  The research and development to provide effective hull antifouling protection is currently being conducted by the Japanese (electrolyzed seawater system) and the Copper Development Association and cooperating companies (90-10 copper-nickel clad steel hull materials development).

B.2.2 Recommendations (Cont'd)

The Navy was spending, in 1974, the sum of $215 million dollar dollars[1] on annual maintenance due to biological fouling and deterioration of piers, docks, and ship hulls only. Additional costs, both in dollars and in loss of operational capability, result from impaired performance and out-of-service time of ships, reduced service life, and reliability of surveillance equipment. In view of the huge costs of fouling to the Navy and its effect on overhaul schedules and the Navy's ability to meet operational goals, it is recommended that system level research and development programs be initiated immediately. Such research and development could benefit significantly by utilizing the results of materials/fouling research programs being conducted by MARAD and independent laboratories, such as F.L. LaQue Laboratory at Wrightsville Beach, N.C. and the experiences of the U.S. Merchant Marine in fouling prevention.

Recommended RDT&E Effort

1. Continue evaluation of U.S. materials development and Japanese system development and integrate with results of materials/fouling research.

   Schedule - Start immediately and reschedule annually.

   Estimated cost - $75,000 annually.

2. Develop prototype full ship hull chlorine antifouling system.

   Schedule - FY 77-FY 79

   Estimated Cost - $600,000

3. Conduct sea trials of ship hull chlorine antifouling system.

   Schedule - FY 79-FY 80

   Estimated Cost - $400,000

B.2.2 Recommendations (Cont'd)

B.2.2.1.2 External Submarine Hulls and Domes.

- Corrosion protection of Navy submarine hulls is currently being provided by anticorrosion paint and zinc galvanic anodes. As stated previously, these anodes provide very little protection while the ship is underway. There are no alternate systems developed to a level of operational acceptability which can be applied immediately to provide a state-of-the-art advancement.

  Impressed current cathodic protection systems appear to be the near-term candidate to replace galvanic anodes. However, development effort is required on these systems to eliminate the detectability characteristics of the external current flows (underwater electric potential), and operational evaluations are required to relate the effect of this system on fire control and sonar systems.

Recommended RDT&E Effort

1. Develop and test current cathodic protection control circuit designs to evaluate UEP affects.

   Schedule - FY 77-FY 78

   Estimated Cost - $225,000

2. Evaluate effect of cathodic protection system output current ripple on fire control and sonar systems.

   Schedule - FY 77-FY 78

   Estimated Cost - $150,000

3. Development and test of SUBSAFE submarine pressure hull and non-pressure hull anode penetration fittings.

   Schedule - FY 77-FY 78

   Estimated Cost - $75,000

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SHIP UNDERWATER MAINTENANCE, EVALUATION, AND REPAIR (SUMER) MAS--ETC(U)
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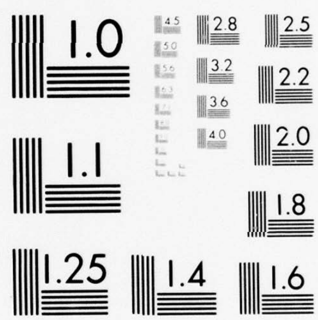


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

B.2.2 Recommendations (Cont'd)

4. Develop aluminum anode material specifications.

   Schedule - FY 77

   Estimated Costs - $40,000

- Fouling protection of Navy submarine hulls is also currently provided exclusively by antifouling paints. There are no supplementary systems developed to a level of operational acceptability to provide fouling protection.

  The Engelhard proposed cell/injection type system of sodium hypochlorite dispersion near the submarine dome with state-of-the-art system is the only candidate system available in the United States. Study efforts and operational tests are required before utilization can be further considered.

  An adaptation of the electrolyzed seawater system developed at the Nagasaki Shipyard in Japan should not be overlooked as a potential candidate for full hull fouling protection.

Recommended RDT&E Effort

1. Conduct a comparative evaluation of the U.S. and Japanese chlorine and the Russian ultrasonic hull antifouling systems.

   Schedule - FY 77-FY 78

   Estimated Cost - $100,000

2. Develop prototype full submarine hull and dome chlorine antifouling system.

   Schedule - FY 77-FY 79

   Estimated Cost - $300,000 (Note: part of development cost is borne by ship system development)

B.2.2 Recommendations (Cont'd)

3. Conduct sea trials of submarine hull chlorine anti-fouling system.

   Schedule - FY 79-FY 80

   Estimated Cost - $400,000

B.2.2.1.3 Sea Chests and Seawater Systems

- Corrosion protection of Navy ship seawater systems is currently provided by techniques such as design inclusion of protective coated piping lengths (galvanized, tinned, or solder wiped), the inclusion of extra-heavy galvanized steel pipe as waster pieces in mixed material piping systems, and the use of fouling protection techniques to minimize corrosion of the concentration cell type. The primary corrosion protection technique involves the use of copper-nickel piping materials. No supplementary techniques have been identified which have been developed to an operational level of readiness.

  Impressed current systems for seawater piping system corrosion protection appear to be in the engineering development stage. Cathodic protection levels established within these systems have been satisfactory. However, much background knowledge relative to the proper anode placement to establish the lengths of protection along the system appears to require development.

Recommended RDT&E Effort

Continue development efforts on impressed current cathodic protection anode placement in systems.

Schedule - FY 77-FY 79

Estimated Cost - $200,000

B.2.2 Recommendations (Cont'd)

- Fouling Protection in Navy ship seawater piping systems has been a matter of ship systems design to provide water velocities in excess of 3 ft./sec. which prevents fouling from forming. During extended periods in port, the main auxiliary seawater circulation systems are drained or operated daily.

  Engelhard/Systems electrolytic hypochlorinators, which are currently available, are the prime candidate for a supplementary system to prevent fouling. These systems prevent fouling by injecting sodium hypochlorite into the sea chest as seawater enters the system. This chlorinated water is subsequently circulated through the system and returned to the sea. These systems require ship installations, for operational evaluation, before full operational readiness can be claimed.

  Although the Engelhard hypochlorinators have a greater history of shipboard successful application, the future potential of the CEPI-COMAV magnetic scale preventing and removing devices and the Aquatron scale and algae removing and preventing systems should be thoroughly evaluated for seawater system antifouling application. See the discussions of the characteristics of these devices and systems in the Discussion Section of this report.

Recommended RDT&E Effort:

The required research and development to ensure an operational capability with existing Navy seawater systems, to provide adequate chlorination levels, and to provide for automatic operation is as follows:

B.2.2 Recommendations (Cont'd)

1. Evaluate through system installation and test, the effect of chlorine on internal system surfaces.

   Schedule - FY 77-FY 78

   Estimated Cost - $100,000

2. Determine adequate chlorine dosing ratio.

   Schedule - FY 77-FY 79

   Estimated Cost - $150,000

3. Evaluate commercially available chlorine measuring instrumentation for use in an automatic feedback chlorination system.

   Schedule - FY 77-FY 79

   Estimated Cost - $60,000

4. Evaluate commercially available magnetic (CEPI-COMAV) and ionization (Aquatron) techniques of preventing marine fouling in seawater systems.

   Schedule - FY 77-FY 79

   Estimated Cost - $300,000

B.2.2.1.4 Recommended Priority of Research and Development. The greatest near term benefit to the Navy in terms of cost pay back, proximity to operational readiness, and need would have the following recommended ranking:

Priority	Research	Cost xK
1.	Develop ship hull chlorine antifouling system	$600
2.	Conduct sea trials of ship hull antifouling system	$400

B.2.2 Recommendations (Cont'd)

Priority	Research	Cost xK
3.	Continue evaluation of U.S. materials (Cu-Ni) development and Japanese electrolyzed seawater system	$ 75 Annually
4.	Conduct evaluation of U.S., Japanese, and Russian hull anti-fouling systems	$100
5.	Evaluate chlorine effect on internal seawater system surfaces	$100
6.	Determine adequate chlorine dosage rate	$150
7.	Evaluate seawater chlorine system feedback instrumentation	$ 60
8.	Evaluate commercial ionization techniques of preventing marine fouling in seawater systems	$300
9.	Develop a corrosion criterion and related data bank.	$300
10.	Evaluate ICCP system UEP on submarines	$ 75
11.	Evaluate C/P system ripple on submarine fire control and sonar systems	$150
12.	Develop submarine pressure hull penetration fittings	$ 75

B.2.2 Recommendations (Cont'd)

Priority	Research	Cost xK
13.	Develop aluminum anode material specifications	$ 40
14.	Develop prototype full submarine hull and dome antifouling system	$300
15.	Conduct sea trials of submarine antifouling system	$400
16.	Continue development of seawater system ICCP corrosion prevention equipment	$200
	Total	$3,325

B.2.2.2 Effectiveness Evaluation Plans. The effectiveness of the antifouling systems from a hull operational point of view should be measured against meeting the objective of no structural repairs and the maintenance of a smooth hull over the life of the ship or submarine.

With reference to hull condition, since corrosion is such a slow process, under the condition of having primary and secondary protection systems applied, inspections of hull condition would be made at periodic overhauls. Assuming that the overhaul periods, where primary protection systems, such as paint coatings, were removed thus exposing the underlying metal surface conditions, occurred every 5 years, this would be the frequency of hull corrosion inspections. Corrosion that would be judged to be likely to cause structural repairs prior to reaching the predicted life of the hull, would be considered as a failure to meet the performance objective. Surface roughness, caused by corrosion, which would result in an increase in ship propulsion power requirements, would be considered as less than fully effective performance of the corrosion protection system. Quantification of the degree of roughness could be established with surface roughness measuring instrumentation, such as, a profilometer (a roughness indicator).

B.2.2 Recommendations (Cont'd)

Hull smoothness evaluations could be made on the basis of comparisons of ship speed versus time out of dry dock curves at constant power or RPM delivered by the propulsion system. A criterion indicative of when hull cleaning due to fouling was required could be used to establish a failure to meet the objective of maintaining a smooth hull over the life of the ship. Two criteria which have recently been proposed to establish the point at which hull fouling removal is required are as follows:

- Proposed Criterion No. 1 - A 5 percent reduction in speed at constant propeller RPM
- Proposed Criterion No. 2 - A 10 percent increase in power at constant ship speed

Upon drydocking the ship, a visual inspection, by an experienced inspection team, should be made to assess the amount of fouling and corrosion causing the speed loss or power increase. Accurate documentation of hard copy and video-audio tape would be obtained on each inspection. A comparative record bank could thus be developed. It is considered that this comparative record bank would provide a reasonable guide to reduce the degree of subjectivity in the evaluations.

The effectiveness of the anticorrosion and antifouling systems, when viewed from the standpoint of operation of the seawater piping systems, could be measured against lower order objectives than when viewed from hull performance point of view.

The specific plan should be formulated after experimental evaluation of a proposed plan. The proposed plan would entail the following:

B.2.2 Recommendations (Cont'd)

1. Make comparative evaluations of records of system parameters. Antifouling system performance degradation to an unacceptable level would be based upon such criteria as:

   a) A 10 percent drop in efficiency of heat transfer units

   b) A 10 percent increase in pressure drop across system components

   c) Visual accumulation of fouling in the sea chests

2. Make periodic inspections of piping system components such as waster pieces. Anticorrosion system performance of an unacceptable level would be based upon a visual determination of the amount of corrosion present in the examined system component.

As in the case of fouling, a video-audio tape and hard copy documentation record bank would provide the means of reducing subjective judgements. A criterion of an unacceptable amount of corrosion would have to be developed.

B.2.2.3 Development Progress Tracking Plans. The development progress tracking plans must consider all of the program elements from the proposed Executive Committees development of policy, budgets, and priorities to the individual system development. As a result of the interfaces between and the interrelationships of the five general areas of concern within the ship Underwater Maintenance, Evaluation, & Repair Master Plan, the Program Manager will have to perform initial management functions, such as:

- Development of overall policy, objectives, and guidelines
- Evaluation of and the setting of priorities
- Establishment of coordination responsibilities
- Establishment of an analysis function

B.2.2 Recommendations (Cont'd)

- Determination and assignment of primary and support activities
- Estimation of program funding requirements
- Performance of budget allocation to primary and support activities
- Establishment of a management function to provide continuing overall program management

The continuing management function should:

- Develop lines of authority and responsibility
- Administer budgetary control
- Develop reporting and monitoring procedures
- Monitor overall and individual program progress
- Conduct overall program coordination activities
- Determine necessary changes in program initiatives

It should be noted that the monitoring of individual and overall program progress is recommended to be centered in one management function. This gives the overall program the overview, coordination, and direction felt necessary for efficient and timely accomplishment of program elements.

The additional program elements foreseen, related to the noncoating protective systems area of concern, are the systems development efforts of (1) the primary activities, (2) the support activities, and (3) the fleet implementation phase of development. The primary area of responsibility for development should involve the U.S. Navy and domestic or foreign commercial interests dependent upon facilities, expertise, proprietary interests, etc. The support areas of responsibility should involve U.S. Navy activities such as all Navy laboratories,

B.2.2 Recommendations (Cont'd)

NSRDC, NAVSEC, NAVSEA, and commercial supporting activities. The fleet implementation phase of development would again involve NAVSEC, NSRDC, and Navy Fleet Commands. Many of the elements of system development are interdependent and consequently must be carried out concurrently or in sequence depending on their relationship. Progress scheduling and tracking, therefore, would involve all levels of responsibility from the overall program manager to all subsequent program elements.

Program development visibility and control could be established through the use of milestone and Pert/Event charting techniques. The implementation and utilization of these techniques is well known and would, with appropriate identification of elements and interrelated events, serve as a progress tracking technique.

B.3.0 DISCUSSION

This section contains results of an in-depth survey of existing techniques and state-of-the-art technology to provide fouling and corrosion protection of ship underwater hull surfaces and seawater piping systems. The survey includes on-going Navy programs, and programs of other U.S. Government Agencies as well as foreign and domestic commercial efforts to provide fouling and corrosion protection.

Hull corrosion and seawater protection systems discussed in the following sections involve sacrificial anodes, impressed current systems, and hull cladding technology. Fouling prevention techniques discussed relating to hull and seawater systems involve a magnetic device, internal systems and external hull chlorine distribution systems, toxin injection systems, hull cladding techniques, and a water ionization system.

The sacrificial anode and impressed current corrosion protection systems are relatively well-developed techniques. Quality control problems exist in the manufacturing of anode materials, along with problems related to environmental impact and the lack of specifications defining the specific characteristics of the anodes, in the case of aluminum anodes. In spite of these problems, these systems are widely used in both military and commercial craft in the United States and foreign countries. The other systems, concepts, or devices discussed are in the research and development stages or the test and engineering development stage.

B.3.1 Introduction

In recent years the number of active ships in the U.S. Fleet has been markedly reduced. The largest proportion consists of submarines and destroyer types. Experience has shown that these ships, because of service conditions, require the most frequent antifouling maintenance. If antifouling coatings lasted twice as long, scheduled drydocking

B.3.1 Introduction (Cont'd)

intervals could be extended. The expected service life of antifouling coatings containing copper toxins, for instance, ranges from 3 to 18 months for submarines in tropical waters to 3 years for surface ships in temperate waters. The relatively long periods in port of Navy ships as opposed to commercial craft allows more rapid and heavy fouling to occur.

Countermeasures to prevent fouling of seawater systems, such as filter screening, daily operation of systems during extended idle periods in port, draining of idle systems, and maintaining system water velocities above 3 feet per second are either not adequate, or are economically impractical. Mechanical removal, such as water lance and chemical cleaning, the method most frequently used for fouling removal, also has shortcomings.

An understanding of the process of corrosion provides an understanding of the nature of the ship's hull, propeller, and appendage corrosion problem.

The tendency for materials to seek a stable state, often that found in nature, is quoted as a fundamental principle. Thus, iron as a dominant element in steel tends to oxidize (release electrons) or corrode to form rust. Metals differ in their energy level or potential for continuing the release of electrons. This is evident from the range of corrosion rates in seawater shown in Table B-1.

> "Higher rates mean the metal yields electrons more vigorously and dissolves away more readily; that is the galvanic reaction proceeds more vigorously. The comparative energy levels are usually expressed in terms of the steady state potential in volts. A more elaborate comparison of metals which may be used in construction of a vessel is listed in Figure B-5. Metals with more negative potentials corrode or dissolve more readily (when coupled with metals of less negative potential). Thus, the voltage of magnesium at -1.64 is indicative of a distinctly more energetic corrosion tendency than a mild steel at -0.62 volts. This difference enables magnesium to protect against corrosion galvanically."[28]

B.3.1 Introduction (Cont'd)

TABLE B-1[28]

REPRESENTATIVE CORROSION RATES IN SEAWATER

Metal	Corrosion Rate in Quiet Seawater(1) Mils per Year	Millimeters per Year
Aluminum	1-50(2)	0.02-1.2
Zinc	1-10	0.02-0.25
Lead	>1-15(2)	>0.02-0-0.38
Iron (Steel)	4-10	0.1-0.25
Silicon Iron	0-3	0-0.07
Stainless Steel	0-5	0-0.12
Copper Alloys	0.5-15(2)	0.01-0.38
Nickel Alloys	0-1	0-0.02
Titanium	Nil	Nil
Silver	Nil	Nil
Platinum	Nil	Nil

Notes: (1) *Rates are ranges of general loss in seawater at ambient* temperatures and velocities no greater than 3 feet (1 M) per second. Pitting penetration is not considered.

(2) Various alloys display widely different rates

At this point, it is important to note that these natural galvanic reactions can result in undesirable drastic corrosion. It occurs when two metals or alloys of different natural corrosion potentials are electrically connected and in contact with seawater (an electrolyte).

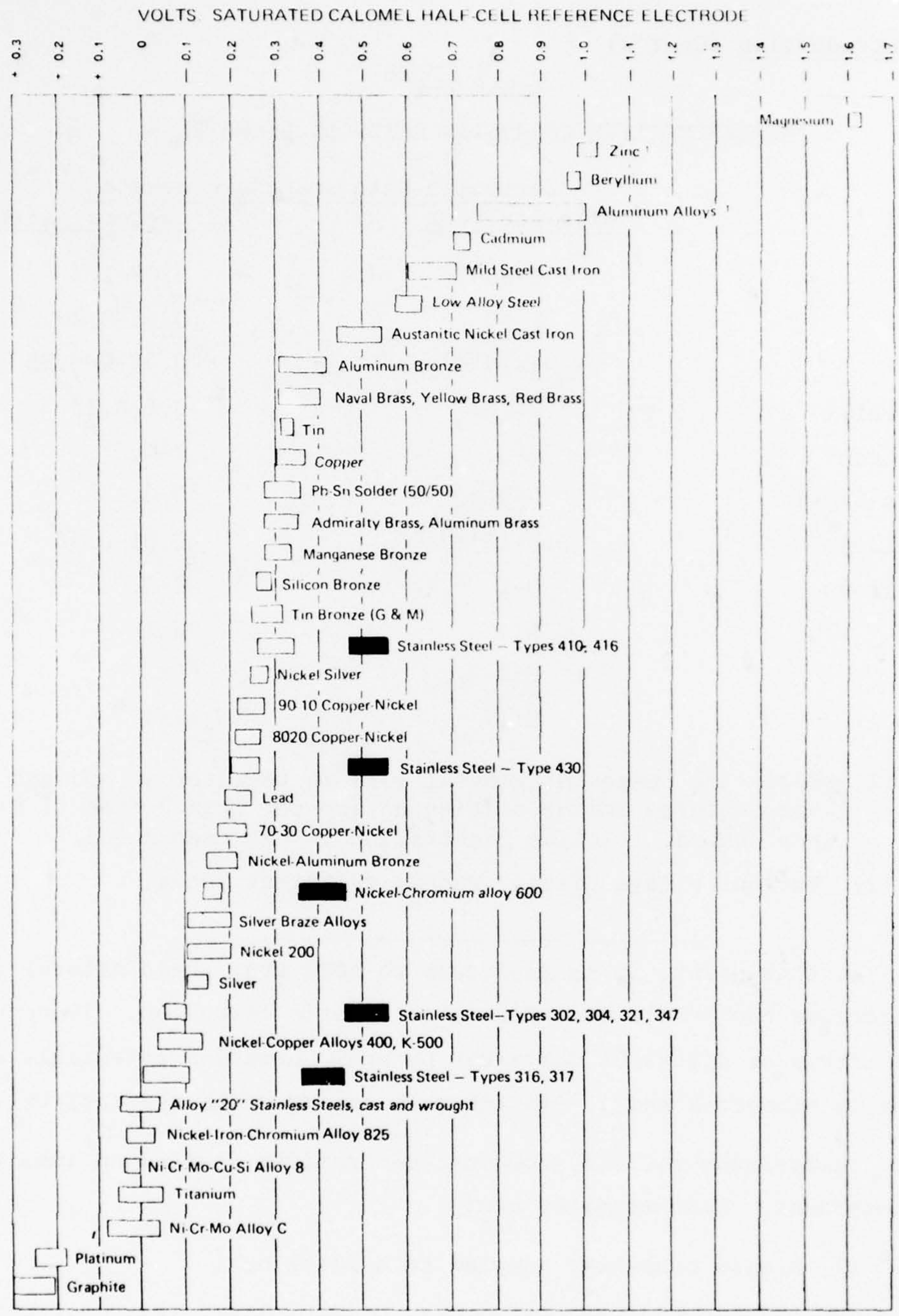
Inadvertent couples, however, can rapidly destroy an important vessel component. Some examples are:

a) Bronze propeller coupled to a steel hull

b) Mill scale on a ship's steel plate, internal or external

c) Steel water boxes coupled to copper-nickel tube sheets of a condenser

B.3.1 Introduction (Cont'd)



Alloys are listed in the order of the potential they exhibit in flowing sea water. Certain alloys indicated by the symbol in low velocity or poorly aerated water, and at shielded areas, may become active and exhibit a potential near −0.5 volts. Data is from Inco Bulletin A404, "Guidelines for Selection of Marine Materials".

[1] The metals are primarily for construction. Anode alloys may be expected to differ.

Figure B-5. Corrosion-Potentials in Flowing Seawater (8 to 13 Ft/Sec) Temp Range 50° - 80°F[27]

B.3.1 Introduction (Cont'd)

d) Bronze impeller in a steel pump casing

e) Brass valve in a steel piping system

f) Aluminum fairwaters fastened to steel hulls

Stray current corrosion has been of concern to the Navy over the past few years. Several incidences of severe corrosion on Navy ship hulls have occurred recently. The possibility that the corrosion was caused by improper grounding during welding has been eliminated in at least some of the cases. Sources of the currents in many instances have not been established. Field studies have been made where the recorded hull potential intermittently showed large fluctuations in the positive direction, which indicated that at some naval berthing sites stray currents did exist. At berthing sites, direct current driven electric trains traveling along finger docks have been considered as potential sources to cause stray D.C. currents which could enter the water and subsequently pass from ship to ship through the water.[15]

Ship seawater system components such as feed tube oil coolers, main condensers, pumps, and other such components experience failures due to corrosion. Companies in the United Kingdom have reported corrosion failures of aluminum brass tubes attributed to erosion corrosion as an example. This type of corrosion damage is attributed to turbulent aerated high velocity seawater. Dissimilar metals throughout the seawater systems also contribute to the corrosion problem. Attempts to combat internal systems corrosion have included rubber linings for water boxes and injection of iron or ferrous sulphate in dosage rates less than 1 part per million to provide protective films over aluminum brass tubes in condensers.[29] In the United States, the Navy installs "waster pieces" in such systems to allow replacement when corrosion occurs in these sections of the system.

B.3.2 Sacrificial Anodes

B.3.2.1 State-of-the-Art. In 1960, the first specifications for galvanic anodes were developed, although they had been in use for many years. In 1963, the Navy shifted to a 3 year drydocking interval, at which time galvanic anodes began to come into more general use. Experimentation with the location of the anodes to provide the most effective protection has resulted in a current practice of placing 60 percent on forward sections of the hull and 40 percent on the aft section. The anodes are normally attached to the bilge keel in a butted arrangement. In essence, the anodes are butted end to end in an array rather than being individually spaced. This arrangement tends to minimize fuel consumption and noise generation by keeping the total number of projections low.

The operational flexibility and efficiency (fuel consumption, noise generation, etc.) of a galvanic system is poor. Flexibility of the system is defined as the system's ability to increase or decrease the emanating current flow under varying conditions of speed and salinity. The operational flexibility is limited since the optimum sacrificial anode system can only be designed for a given ship operating speed.

The "three year" zinc system currently specified by the U.S. Navy has normally provided complete cathodic protection while the ship is moored or moving at speeds up to 5 knots. Much of the time that the ship is underway, it receives only partial protection from anodes installed. Also, the phenomenon of increasing exposed areas of metal and the development of porosity of the paint films with increasing time out of drydock increases the current density demands on the anodes in order to provide protection with increasing intervals between drydockings. A current density value of 3.9 milliamperes per sq. ft. of hull area has been used by the Navy for a 3 year interval installation. Figure B-6 contains curves relating expense (installation cost plus projected upkeep for the life of anode) per sq. ft. of hull area to provide the cathodic protection (C/P) current required. It can be seen from

B.3.2 Sacrificial Anodes (Cont'd)

Figure B-6 that a current density of 5.2 milliamperes per sq. ft. necessary for a 4 year drydock cycle is not within the optimum cost range for corrosion control using a zinc system. However, a sacrificial system using aluminum anodes can provide a 4 year period of protection at a minimum cost.

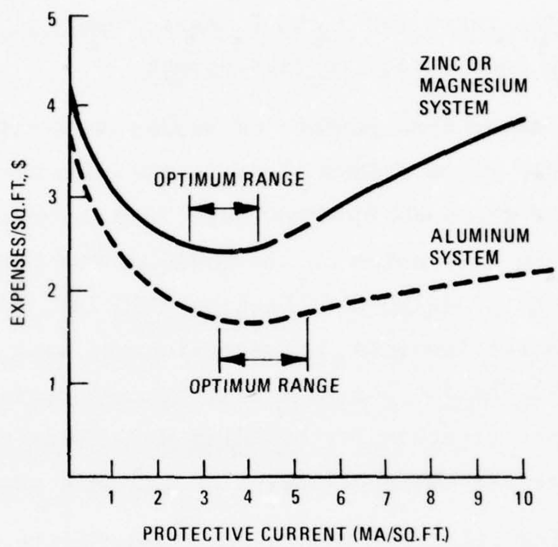


Figure B-6. Expense Per Square Foot for Galvanic Anode Cathodic Protection[8]

Based upon a number of unstatisfactory service reports of magnesium anodes used on a 3 year basis, these anodes are limited to a 2 year drydocking cycle. The magnesium anodes are only 50 percent efficient in seawater. Consequently, half the anode deteriorates in seawater without providing useful protection. Additionally, the high potential of magnesium necessitates the use of dielectric shields on the hull beneath and at least 2 feet around the periphery of the anode array.

B.3.2 <u>Sacrificial Anodes</u> (Cont'd)

Aluminum anodes provide an installation advantage due to their light weight and high current output. On a weight basis they can provide 3 times the current per pound when compared with zinc. Equivalent surface areas of aluminum and zinc have approximately the same current output. Galvanic anodes are specified in the NAVSHIPS Technical Manual, Chapter 9190. The zinc and magnesium anode quantities for stern area and complete systems are life rated for 3 and 2 years, respectively. Specifications for aluminum anodes require development.

The installation arrangements of anodes on a ship are normally identified on the ship plans (class plans in the case of Navy ships). The identification of the number, type, size, and current output are specified for existing Navy ships on the basis of the "wetted surface"[30] of the hull. NAVSHIPS 0901-190-002, Section 9190.232, identifies the specific utilization requirements for magnesium and zinc anodes. Aluminum anodes are evaluated for use on a case by case basis. For new construction, the Specification for Building Navy Ships contains a Section 633 which delineates the application of galvanic anodes.

> "Aluminum (sacrificial) anodes are commercially available from Alcoa, Reynolds, and many other smelters under Dow license and are being used for cathodic protection by some ship owners. The test program undertaken by the Navy on various types of aluminum anodes indicates that thus far only one aluminum alloy composition containing a trace amount of mercury has proven reliable in both laboratory and service tests. Small variations in grain size, heat treatments, impurities, and other variables associated with other aluminum anode compositions have resulted in erratic performance. The mercury bearing anode is undergoing further service evaluation, as well as further laboratory testing to determine, among other things, the effect the mercury will have on non-ferrous alloys. Upon successful completion of this test program, a specification will be written for the procurement of aluminum anodes."[2]

B.3.2 Sacrificial Anodes (Cont'd)

B.3.2.2 Technology Gaps. The technological gap that exists is the lack of identification of environmentally acceptable anode compositions which do not contain the toxic material, cadmium, and toxic compound forming material, mercury.

B.3.2.3 Needed RDT&E. The required research includes the development of environmentally acceptable zinc and aluminum anode assemblies.

B.3.2.4 Environmental Considerations. The environmental concern is that zinc anodes, which are the primary anode material in use today, contain cadmium, and the aluminum anodes contain mercury, which forms toxic organic mercury compounds. Fortunately, at present there are no known cases of EPA serious concern about the introduction of these toxic compounds into navigable waters.

B.3.2.5 Personnel Considerations. There are no training and manning requirements for operation and maintenance since, after installation, galvanic anodes perform cathodic protection through the process of galvanic anode material dissipation. They are replaced during periodic maintenance availabilities.

B.3.2.6 Equipment Support. Support equipment consists simply of replacement anodes, welding and painting facilities.

B.3.2.7 Effectiveness Evaluation Plan. Performance effectiveness evaluations of the anode assemblies have been performed by shipyard inspection crews during drydock periods. Their interest has been the occurrence or lack of occurrence of corrosion. The inspectors also note the condition of the anode materials and, if required, the anodes are replaced.

Based upon the Effectiveness Evaluation Plan presented in Paragraph B.2.2.2, it is recommended that a measure of the protected area surface roughness be established through the use of profilometer

B.3.2 Sacrificial Anodes (Cont'd)

or similar instrument during the inspection. This quantitative value may then be used to evaluate the degree of effectiveness of corrosion protection actually achieved.

B.3.2.8 Development Progress Tracking Plans. The tracking of anode research and development effort worldwide is considered necessary to ensure that the U.S. Navy has the most environmentally acceptable and consistently performing anode materials that technology can supply. This subject has been discussed at a higher topic level in this study (see Paragraph B.2.2.3).

B.3.3 Impressed Current Cathodic Protection Systems

B.3.3.1 State-of-the-Art. In order to provide the necessary supplementary protection over the underwater hull coating system, the U.S. Navy has installed approximately 160 Engelhard produced Navy systems on its surface fleet ships and is currently retrofitting others. Outside of one or two Lockheed type systems evaluated, this is the only type of industrially produced, impressed current system which has been used on Navy surface ships.

The use of protective coating systems considerably reduces the area of bare metal requiring cathodic protection and the amount of protective current required. Research has shown that bare steel immersed in quiet seawater requires 4 to 6 milliamperes (ma) per sq. ft. of steel surface for complete protection. This would amount to about 265 amps for the bare hull of a vessel with a wetted surface of over 53,000 sq. ft. In actual practice, the insulating effect of the hull anticorrosion and antifouling paint coatings could reduce the current required for full protection to about 4 amps.[31]

The impressed current cathodic protection systems used by the U.S. Navy and commercial shipping on large active ships consists of anode assemblies (number dependent on ship size), insulating shields at the point of anode attachment to the hull, a control unit, a power supply, and a reference cell.

B.3.3 Impressed Current Cathodic Protection Systems (Cont'd)

Systems of this type are applicable to large ocean-going vessels and are, therefore, generally operated from 60-cycle alternating current. This makes it possible to deliver high voltage power to remote anodes through the 440 volt 3 phase distribution lines already available in the ship. This is an important consideration since anodes may draw as much as 150 amperes at low voltage and the distribution of such current would present a real problem.

The power supply component receives the relatively high voltage at the anode location and transforms and rectifies it through several diodes to supply direct current at the anodes. The power supply consists of a saturable reactor with several diodes for power control. A suitable indicating meter permits observation of each local power supply. This equipment should deliver the proper electrical power to protect the hull no matter what speed, salinity, or paint condition may be encountered.[31]

Navy anodes are a platinum clad tantalum wire mounted on a rectangular frame. The plastic frames are mounted on a neoprene shield which is faired with and surrounded by a "capastic" material shield which is applied over the painted surface of the hull. Navy platinum clad anodes are rated at 75 to 150 amps (Types I and II).

The majority of ocean service size ships have two anodes mounted on the hull in the stern area plus four in forward sections of the hull. The anodes are located below the light waterline forward of the propeller plane. The silver-silver chloride reference cell is located to give an accurate potential on the hull. On four anode installations, a reference cell is located midway between each pair of anodes on both sides of the hull.

An ICCP system makes use of a reference electrode to regulate the current output. The electrode is made of metal/metal-salt combination (e.g., silver mesh coated with silver chloride) which exhibits a stable potential in seawater. The potential of the hull is compared to this reference cell. A change in the hull potential of the

B.3.3 <u>Impressed Current Cathodic Protection Systems</u> (Cont'd)

ship hull due to the impressed protective current is reflected in a shift in the potential difference measured relative to the reference electrode. A marked change in the potential occurs when full protection (polarization) is achieved. Experience has shown that a potential of 0.85 V for steel indicates complete protection. Experience has also shown that these systems tend to hunt above and below the current densities required to provide the desired hull polarization level when first energized dependent upon paint condition. This is a short-term characteristic and is not considered a system problem requiring current action. This change in potential measured by the reference electrode is used as a basis of control of the current output of the power source.

The control unit is the "brain" of the ICCP system. The voltage signal obtained between the reference electrode and the hull is compared with a preset voltage in the power control unit. If the reference voltage is smaller than the preset voltage, the control unit will increase the anode current until the reference potential and the preset potential are equal, and vice versa. In this manner, an optimum hull potential is maintained at all times.

Ship propellers, being constructed of materials different than the hull, are often cathodic relative to an anodic steel hull surface. To ensure cathodic protection of the propeller, the shaft is grounded to the hull of the ship. Current drains of 10 amperes and more are commonly carried by the grounding system. Thus, the current provided to the stern area of the ship and propeller assemblies through the water by the anodes is effective in preventing corrosion.

Engelhard Cathodic Protection Automatically Controlled (CAPAC) systems are provided in three classes of equipment suitable for installation on craft from pleasure size to the largest Naval vessels.

B.3.3 Impressed Current Cathodic Protection Systems (Cont'd)

The total cost of installing a CAPAC system is dependent largely on the installation costs. The material costs of a six anode system, such as would be used on a DD-963 Class Destroyer[32] would be $13,000. After adding the installation costs, the total cost would be approximately $30,000. The material costs for a carrier would be $30,000 to $45,000. The complete SHIPALT has been costed out at $350,000.[25]

Surface-effect ships are very weight-critical. Therefore, aluminum alloys are used in major structural applications, including external plating on the sidewalls. In contrast, auxiliary structures such as rudders, stabilizers, and propulsion equipment frequently require materials with higher strengths than aluminum. Since aluminum alloys are anodic to all major structural metals in seawater, use of these high-strength materials will establish galvanic couples that will accelerate corrosion of the aluminum hull plating, with possible loss of watertight integrity.

To prevent this adverse galvanic action, cathodic protection should be employed. The action of a cathodic protection system is to polarize the cathodic materials (high-strength alloys) to the protective potential of the aluminum hull plating, thereby eliminating the driving force for the galvanic attack. A design investigation has been conducted to establish design parameters for an active, impressed current C/P system for these high velocity hulls. This study has identified a number of areas where future research is required (see Paragraph B.3.3.3).

B.3.3.2 Gaps in Technology. The design requirements of impressed current C/P systems, i.e., the minimum current requirements, the number of controllers, and the number of reference cells and anodes, are determined based upon the wetted surface of the vessel to be protected. This is a relatively rough technique. Also, the adequacy of the level of protection is based upon predetermined polarization voltage level of the surface to be protected. A reference cell in the impressed current system maintains the hull potential at a preset value during operation

B.3.3 Impressed Current Cathodic Protection Systems (Cont'd)

of the ship. Obviously, none of these predictive techniques nor the hull potential maintenance system actually measure the rate of corrosion. Instruments to effectively measure the instantaneous corrosion rate do not appear to be available. A meter known as "Rust Reader," developed by Morgan Berkeley Ltd, Winchester, Hants, is currently in use within SSBN submarine domes to indicate the voltage differences between a silver-silver chloride cell in the "Rust Reader" and metallic hull surfaces of the AN/BQR-20 sonar. This instrument, however, does not indicate the "corrosion rate." Refined techniques of establishing the number of anodes required are also seen as required by DTNSRDC.[33]

Another area requiring development effort is in the development of dielectric shield materials which are less susceptible to surface failure than existing materials. This is particularly important in the application of impressed current systems to aluminum hulled craft such as hydrofoils and surface effect ships. The problem of over protection of the aluminum hull at the point of shield failure could cause structural failure of the aluminum.

Operational problems exist in the use of impressed current systems on aluminum hulled craft. For instance, the use of various materials such as 17-4 PH stainless, 5456 aluminum, Inconel 625, and titanium on the same craft creates complex corrosion protection problems in the area of current levels required and the location of anodes to provide optimum protection without achieving over protection, or hydrogen embrittlement (stress corrosion) of high strength steels. Additional development effort is needed to define installation design criteria on hydrofoils and surface effect ships.

Impressed current C/P systems are not currently being installed on submarines because of two basic problem areas. Satisfactory submarine hull penetration fittings for anode attachment have not been identified and require design development. The effect of the ripple of the current emanating from the C/P system, with passive filter

B.3.3 Impressed Current Cathodic Protection Systems (Cont'd)

installed, on the submarine underwater electric potential signature, and fire control and sonar sensors has not been fully evaluated. Therefore, research and development is required in both of these areas. Then, if the current ripple is found to be unacceptable, additional research effort using active filters should be directed toward reduction of the ripple.

B.3.3.3 Required Research. Research and development efforts are required to develop effective corrosion monitoring instrumentation to evaluate the protection systems on surface ship hulls.

Evaluation programs are needed to determine the effect of electrical current ripple of currents emanating from anodes on submarines in the following areas:

- Underwater electric potential
- Impact on sonar sensors
- Impact on fire control systems

A program is needed to develop and evaluate a SUBSAFE submarine hull penetration fitting or a non-pressure hull alternate fitting for anode attachment.

Additional recommended research to support surface effect ships effective application of impressed current C/P systems is as follows:[7]

- Remote Anode Studies. Conduct a feasibility study and develop a working design for a remote anode system to be used on SES. Use of such an anode would eliminate the dielectric shield and associated problems and provide a more uniform distribution of anode current, and mitigate some of the hydrogen embrittlement problems of high-strength steels.

B.3.3 Impressed Current Cathodic Protection Systems (Cont'd)

- Effect of Protection Potentials on Titanium and 17-4 PH Stainless Steel. Conduct experiments to determine if the highly electronegative potentials associated with a cathodic protection system will induce adverse effects such as hydrogen embrittlement on the 17-4 PH stainless steel SES appendages.

- Effect of Seawater Temperature on Protection Current Densities. Conduct systematic experiments to determine the effect of seawater temperature on the protection current density of SES materials.

- Hull Anode Design. Design a streamlined hull-mounted anode for SES use which will have minimum drag and cavitation characteristics combined with high current capabilities and long life.

- Controller and Power Supply Design. Design a controller and power supply which are compatible with SES. Both units should operate from craft power, 28 volts, 60 Hertz. The controller should have provisions for current suppression if the reference cell at the shield edge exceeds -1.5 volts, and should be fail-safe. The power supply should be of the SCR type with maximum current limiting circuitry and current bypass circuitry to allow reduction of output to zero amperes.

- Velocity Effects on Dielectric Shield Materials. Determine the effects of high velocities on the candidate dielectric shield materials. Determine the optimum shield edge configuration to minimize the possibility of shield damage.

B.3.3 Impressed Current Cathodic Protection Systems (Cont'd)

- Pilot System. Install a pilot impressed current cathodic protection system onboard a 100-ton SES, preferably the SES-100B, in order to verify the design methodology and current data, and to gain operational experience on such a system before installation on the 2000-ton SES.

B.3.3.4 Environmental Considerations. In cathodic protection systems, the point in the system where current discharges into navigable waters would occur is at the anodes. Mr. Robert Baboian, Manager of the Electrochemical and Corrosion Laboratory at Texas Instruments Incorporated, Attleboro, Massachusetts, has identified the anodic reactions on platinum in seawater. Since the Engelhard cathodic protection system presently installed on U.S. Navy ships utilizes platinum c anode assemblies, the following reactions are typical.

Under any condition in seawater, the following reactions occur or can occur:[34]

a. Primary anodic reaction on platinum in seawater involves dissociation of seawater to yield chloride ions which forms chlorine.

b. Another reaction that can occur in a chloride environment is that hypochlorous acid can be developed.

c. Ionization of hypochlorous acid gives hypochlorite ions and hydrogen ions.

It should be noted that chlorine is formed as a product of the primary anodic reaction. Chlorine is identified as a toxic substance within the Hazardous Substances List of the EPA in either the gaseous or liquid form. It is also identified in the (A) category in the EPA Harmful Quantity Categories. (See Annex B-2.) This means that if chlorine generation is in excess of 1 part per million (ppm), an EPA violation would occur.

B.3.3 Impressed Current Cathodic Protection Systems (Cont'd)

It should be noted that hypochlorite ions are formed in the above reactions. It is also known that electrolytically treated seawater such as occurs in the Engelhard Chloropac chlorinator results in the production of sodium hypochlorite. This compound may also be developed at the anode and is listed in the Hazardous Substance List Harmful Quantities Category (A). Again, the generated quantities must be less than 1 ppm to be within the EPA requirements.

Since no reference can be located identifying the quantities of these compounds generated at the impressed current anodes, it is questionable whether an EPA violation could be cited.

B.3.3.5 Personnel Considerations. The Engelhard impressed current C/P system can be operated, monitored, and maintained by one man. For Navy ship installations of these systems, an Interior Communications (IC) technician and an Electronic Mate (EM) are trained to provide the necessary skills to perform these tasks.

Training is provided at the installing shipyard by ships design and test personnel. Navy training films, shipboard system test procedures, and the manufacturer's equipment manual are used to present the training. The normal training period is three hours. This is considered to be significantly too short.

Operating and monitoring time requires only ten minuts per day, while maintenance is performed on an infrequent basis as required.

Recommendation

Recommendations previously made should be pursued, that a class "C" course be established on both the East Coast (Portsmouth, Va.) and the West Coast (Long Beach, Calif.)

B.3.3 Impressed Current Cathodic Protection Systems (Cont'd)

This is considered necessary to improve operation and maintenance personnel knowledge of system equipment characteristics, and to prevent the occurrence of system misuse. It is also considered necessary to ensure that the system operating safety precautions are understood.

B.3.3.6 Equipment Support. No spare parts are requested by the Navy for the Engelhard-produced Navy system.

The test and maintenance equipment consists of a volt-ohmmeter (VOM) and small hand tools, normally available onboard ship.

B.3.3.7 Effectiveness Evaluation Plan. Performance effectiveness evaluations have been performed by shipyard inspection crews during drydock periods. Their interest has been the occurrence or lack of occurrence of corrosion on the protected areas and the frequency and general degree of corrosion. The inspectors also note the condition of the anodes and anode shields and, if required, the anodes or shields are replaced.

Based upon the Effectiveness Evaluation Plan presented in Paragraph B.2.2.2, it is recommended that a measure of the protected area surface roughness be established through the use of a profilometer or similar instrument during the inspection. This quantitative value may then be used to evaluate the degree of effectiveness of corrosion protection actually achieved.

B.3.3.8 Development Progress Tracking Plans. The tracking of impressed current cathodic protection research and development efforts worldwide is considered necessary to ensure that the U.S. Navy has the most acceptable and consistently performing systems that technology can supply. This subject has been discussed in greater detail at a higher topic level in this study (see Paragraph B.2.2.3).

B.3.4 Fouling Control via Chlorine Distribution in Seawater Piping Systems

B.3.4.1 State-of-the-Art. Fouling control in U.S. Navy ships' seawater piping systems has been largely a matter of designing the piping systems so as to provide for seawater velocities in excess of 3 ft./sec. Electrolytic hypochlorinators, such as the Engelhard "Chlorapac" system, are currently available and used in numerous land-based and commercial shipboard installations.

To be effective, a reliable supply of hypochlorite is needed intermittently. It is needed to keep mollusks, algae, slime, and marine growths of all kinds from thriving in the sea chests and invading the ships' seawater systems, where they cause destructive turbulence at inlets, block pipes, and retard heat transfer in tubes. Chlorination protection is needed wherever seawater is used, i.e., condenser cooling and general engine room services, circulating water in ship's air conditioning system, fire system, and seawater piping throughout the vessel. Electrolytic decomposition of seawater eliminates the need to carry hazardous gas equipment on board or to give up payload space to bulk storage of commercial sodium hypochlorite or other treatment chemicals.

The Engelhard "Chloropac" system was originally designed specifically for shipboard use. Power supply and generating cells are separately housed for optimized installation. No backflush is needed to keep the system working at capacity. Chloropac generating cells are completely corrosion resistant. They are made of flanged titanium pipe, accurately spaced by inert plastic insulating supports and assembled with stainless hardware. The platinized titanium anode is coated with 200 microinches of platinum, adequate for long life on seawater operation, and conservatively rated for five years. Longer-life anodes can be supplied for special conditions. The cells are assembled in pairs and arranged electrically in series. Low voltage power is fed

B.3.4 Fouling Control via Chlorine Distribution in Seawater Piping Systems (Cont'd)

to the center two cell assemblies, from which the assemblies at each end draw their power, an arrangement assuring maximum rectification efficiency and preventing possibility of stray current corrosion, as the electrical potential at inlet exactly equals potential at outlet. Cells have a design operating pressure of 150 psi at 180°F and will withstand test pressures of 1000 psi (burst pressure of titanium pipe is 7000 psi). Power supplies for the Engelhard 5-5M and 5-10M models operate on 120 V, 1Ø, 60 Hz input. Models 10-20M, 10-40M, and 10-60M operate on 440 V, 3Ø, 60 Hz, input.

The marine shipboard systems are rated and priced as follows:

Engelhard Model Number	Equivalent Chlorine Capacity Lbs./Hrs.	Export Price [35]
5-5M	1/2	$ 3,800
5-10M	1	5,290
10-20M	2	7,425
10-40M	4	11,300
10-60M	6	15,000

The above capacities are equivalent to ratings for seawater systems with rated flows of 2,000 to 24,000 GPM. Multiple systems have been installed to provide up to 3250 pounds of equivalent chlorine per day.

Chloropac systems are installed on numerous land-based commercial installations and on U.S., foreign military, and commercial ships. The U.S. military shipboard installation is on the Military Sealift Command vessel USNS WHEELING. The foreign countries where shipboard installations have been made include Venezuela, Iran (Navy), England, Saudi Arabia, and South Africa.

B.3.4 Fouling Control via Chlorine Distribution in Seawater Piping Systems (Cont'd)

The U.S. Navy has purchased equipment for an installation of an electrochemical chlorine system on a FF-1052 class ship for operational tests. The installation and testing has not been started due, reportedly, to a lack of adequate funding.

B.3.4.2 Technology Gaps. Technologcal deficiencies inherent in these systems would have to be resolved in the following areas:

1. The effect of electrochemically generated chlorine on ships' seawater systems
2. Determination of effective hypochlorite dosing rates
3. The development of a sensor for monitoring effective chlorine and for providing automatic system control

B.3.4.3 Needed RDT&E. The required research and development to ensure an operational capability with existing Navy seawater systems, identified to fill the technology gaps, are as follows:

1. Evaluate through system installation and test the effect of chlorine on internal piping system components
2. Determine adequate hypochlorite dosing rates
3. Evaluate commercially available chlorine measuring instrumentation for use in an automatic feedback chlorination system

The above RDT&E required effort was expanded upon in a letter from the Commander, Naval Ship Engineering Center, to the Commander, Naval Sea Systems Command (SEA 03), as follows:

> "Technology Deficiencies for Navy Application of Electrochemical Fouling Control Systems.

B.3.4 <u>Fouling Control via Chlorine Distribution in Seawater Piping Systems</u> (Cont'd)

a. Effect on Navy Shipboard Systems - Operational information is available for some materials under some conditions, but long term information which would correspond to the Navy ship operation is not available. Hypochlorite solution can be aggressive to the metals used in ship piping systems. Investigation should be made to determine the influence on Navy ship systems of varying chlorine concentrations. The parameters in this investigation include temperature of waters, concentration of chlorine, cyclic operation, etc. The investigation should also include materials applicable to the hypochlorite distribution piping.

b. Determination of Hypochlorite Quantitites and Effective Operating Cycles for Fouling Control - Marine organisms can attach [primarily] to surfaces [where slime films remain only] under stagnant or slow moving conditions. The fouling problem is more severe on Navy ships vice commercial ships because Navy ships spend a greater portion of their time moored or at dock. The chlorine generator operational requirements for Navy ships would thereby be different from commercial demands. In this phase of the task the minimum hypochlorite solution and cyclic operation necessary to prevent fouling would be determined by studies at an immersion test facility. This would ensure that unnecessary power is not wasted to generate chlorine nor would the piping system be exposed to more chlorine than is necessary.

c. Availability of Chlorine Sensors for Monitoring and Automating the System - The manual or cyclic programmed system will prevent fouling, but could result in occasional high concentrations of chlorine which waste power and may mildly attack some metal surfaces. Automatic control would eliminate this problem and also eliminate most ship operational requirements. In the past this type sensor was not available, but recently a cell has been put on the market which could be applicable to chlorinated shipboard seawater systems. At this time the manufacturer of this sensor only makes provisional performance claims. With laboratory development as proposed it could provide the monitoring capability necessary to control the chlorination system."[36]

B.3.4 Fouling Control via Chlorine Distribution in Seawater Piping Systems (Cont'd)

B.3.4.4 Environmental Considerations. The environmental problems associated with the use of this type of system will depend on the dosage rates of chlorine found necessary to provide effective fouling control. The manufacturer's literature recommends a dosage rate of 0.5 parts per million on a continuous basis. This rate of chlorine generation in navigable waters would be within the EPA requirements for hazardous substances. However, if the effective dosage rates for Navy shipboard use are found to exceed 1 ppm, an EPA violation could be cited. No OSHA violations can be seen to be involved.

B.3.4.5 Personnel Considerations. The personnel required to operate and maintain the systems equipment is limited to two people, one to energize and monitor system operation, and one to perform infrequent maintenance operations.

The training, duration of training, number of personnel and skill types, and the operation and manning requirements are similar to those required for the impressed current cathodic protection system identified in Section B.3.3.

B.3.4.6 Equipment Support. Equipment support required consists of a volt-ohm meter and hardware-related small tools.

B.3.4.7 Effectiveness Evaluation Plan. The specific plan should be formulated after experimental evaluation of a proposed plan. The proposed plan would entail the following:

1. Make comparative evaluations of records of system parameters. Antifouling system performance degradation to an unacceptable level would be based upon such criteria as:

B.3.4 Fouling Control via Chlorine Distribution in Seawater Piping Systems (Cont'd)

a) A 10 percent drop in efficiency of heat transfer units

b) A 10 percent increase in pressure drop across system components

c) Visual accumulation of fouling in the sea chests

A video-audio tape and hard copy documentation record bank would provide the means of avoiding subjective judgments. A criterion of an unacceptable amount of corrosion would have to be developed.

B.3.4.8 Development Progress Tracking Plan. The development progress tracking plan, seen to fall within the total context of the tracking effort, would be specifically related to the development of the electrochemical chlorine AF system described above.

B.3.5 TOXION TWO Seawater Antifouling System

B.3.5.1 State-of-the-Art. A British manufacturer, F.A. Hughes and Company, Ltd., Surrey, England, has developed a new saltwater fouling control system. This system, known as the TOXION-TWO System, is capable of treating up to 30,000 tons of seawater an hour.[37] It provides fouling protection by injecting an organic tin-based antifoulant, mixed with freshwater, into the inlet water boxes (sea chests) of the ship's seawater system.

The system is contained in a free standing cubical case approximately 36" x 23" x 43". The main components of the TOXION TWO system are a storage tank, a stirring device, a distribution metering pump, and an electrical control panel. Up to six pumpheads can be accommodated, each of which has a separate micrometer adjustment capable of metering the freshwater and antifoulant mixture to a final injection level of 0.003 ppm (parts per million) of the tin-based toxicant in the seawater.

B.3.5 TOXION TWO Seawater Antifouling System (Cont'd)

The electrical power to the system can be supplied by a 220 V single phase 50 or 60 Hz, 750 volt-amp source.

This system is currently used on large tankers and bulk carriers in European waters. The system is suitable for and capable of being applied to any size vessel. The maintenance on the system is limited to pump maintenance and topping the storage tank with toxicant.

The purchase and installation costs for the system have not been supplied but could be considered to be extremely nominal per installation. Typical system operating costs based upon 1974 dollars are shown in Table B-2.

B.3.5.2 Technology Gaps. Technology gaps which exist involve a determination of affect of the TOXION-TWO antifoulant upon U.S. Navy ship seawater systems.

B.3.5.3 Needed RDT&E. The needed test and evaluation involves the evaluation of the effect of the TOXION-TWO toxicant upon Navy ship seawater system components. Development of automatic feedback control of the system would also be desirable.

B.3.5.4 Environmental Considerations. No environmental problems are anticipated related to the use of this system. The singular organic tin compound, stannous floride, listed in the EPA Hazardous Substances List, is identified as a category "D" substance. This category of substances is not prohibited up to 100 parts per million (ppm). The final effluent discharge from this system conforms to the International Maritime Consultative Organization (IMCO)[37] and the United Kingdom Department of Trade.[20]

B.3.5 TOXION TWO Seawater Antifouling System (Cont'd)

TABLE B-2

"TOXION TWO" INLET BOX SYSTEM

TYPICAL RUNNING COSTS

EXAMPLE 1	15,000 DWT CARGO VESSEL	TWO INLET BOX SYSTEM
Cooling Water Flow	Approx. 2000 m^3/hr	Main Inlet
" " "	" 1000 m^3/hr	Auxiliary Inlet
Toxion Two/Freshwater	Mixture Ratio 1:15	
Dosage of Toxion Mixture	1.00 Lit/hr	Main Inlet
" " " "	0.50 Lit/hr	Auxiliary Inlet
Toxion Mixture Consumption	36 Lit/day	
Toxion Fluid Consumption	36/16=2.25 Lit/day	

At £2.45 per lit. Daily Cost = £2.45 x 2.25 = £5.53

Assuming ship is alongside for say 100 days per year, the annual cost

= £100 x 5.53 = £553.00 Approx.

EXAMPLE 2	100,000 DWT TANKER	SINGLE INLET BOX SYSTEM
Cooling Water Flow	7,000 m^3/hr	Main Inlet
Toxion Two/Freshwater	Mixture ratio 1:5	
Dosage of Toxion Mixture	1:5 Lit/hr	
Toxion Mixture Consumption	27 Lit/day	
Toxion Fluid Consumption	17/6 = 4.5 Lit/day	

At £2.45 per lit Daily Cost = £4.5 x 2.45 = £11.02

Assuming ship is alongside for say 25 days per year, annual cost

= £25 x 11.02 = £275.50 Approx.

EXAMPLE 3	250,000 DWT VLCC	TWO INLET BOX SYSTEM
Cooling Water Flow	9,000 m^3/hr	Main Inlet
" " "	4,000 m^3/hr	Auxiliary Inlet
Toxion Two/Freshwater	Mixture ratio 1:10	
Dosage of Toxion Mixture	3 Lit/hr	Main Inlet
" " " "	1.3 Lit/hr	Auxiliary Inlet
Toxion Mixture Consumption	79.2 Lit/hr	
Toxion Fluid Consumption	79.211 = 7.2 Lit/day	

At £2.45 per lit Daily Cost = £7.2 x 2.45 = £17.64

Assuming ship is alongside for 25 days per year, annual cost

= £25 x 17.64 = £441.00 Approx.

B.3.5 TOXION TWO Seawater Antifouling System (Cont'd)

B.3.5.5 Personnel Considerations. The personnel required to operate and maintain the systems equipment is limited to two people, one to energize and monitor system operation, and one to perform infrequent maintenance operations.

B.3.5.6 Equipment Support. Equipment support required consists of onboard small tools.

B.3.5.7 Effectiveness Evaluation Plan. The specific plan should be formulated after experimental evaluation of a proposed plan. The proposed plan would duplicate that required for fouling control via chlorine distribution in seawater piping systems.

B.3.5.8 Development Progress Tracking Plan. The development progress tracking plan is seen to fall within the total context of the general plan described in Paragraph B.2.2.4. All elements of tracking effort would be specifically related to the development of the TOXION-TWO system described above.

B.3.6 Electrolyzed Seawater Hull Fouling Prevention System

B.3.6.1 State-of-the-Art. This system to prevent ship hull fouling was developed at the Nagasaki Shipyard in Japan by Mitsubishi Heavy Industries, Ltd. The system electrolytically develops chlorine from seawater and, after combining the chlorine laden seawater with pressurized air, delivers the mixture through nozzle pipes fitted to the bilge parts of the hull. The mixture rises up to the surface along the ship's side hull plates as a minute bubble screen type flow. The antifouling effect of this system has been confirmed on a 50,000 ton ore carrier.

Design improvements on this system and analysis of the application to a 250,000 ton tanker show that the system is practical and economically justifiable based on a three year cost pay back test normally used in the shipping industry. The current designs are estimated to have an 8 to 10 year service life with minimal maintenance requirements.

Magnesium hydroxide separated from the seawater is collected in holding tanks. The hydrogen separated is passed through an anti-explosion filter and enters a ventilation fan duct, where it is diluted.

Large tankers and ore carriers, if docked at 12-month intervals, would, per the analysis, gain 0.5 and 1.0 knots, respectively, in service speed due to electrolytic seawater protection.[21]

The electrolytic antifouling system, as shown in Figure B-7, is principally composed of:

(1) Seawater pump with piping

(2) Electrolyzer

(3) Rectifier

(4) Cyclone

(5) Air Compressor with air piping

(6) Nozzle pipe

B.3.6 Electrolyzed Seawater Hull Fouling Prevention System (Cont'd)

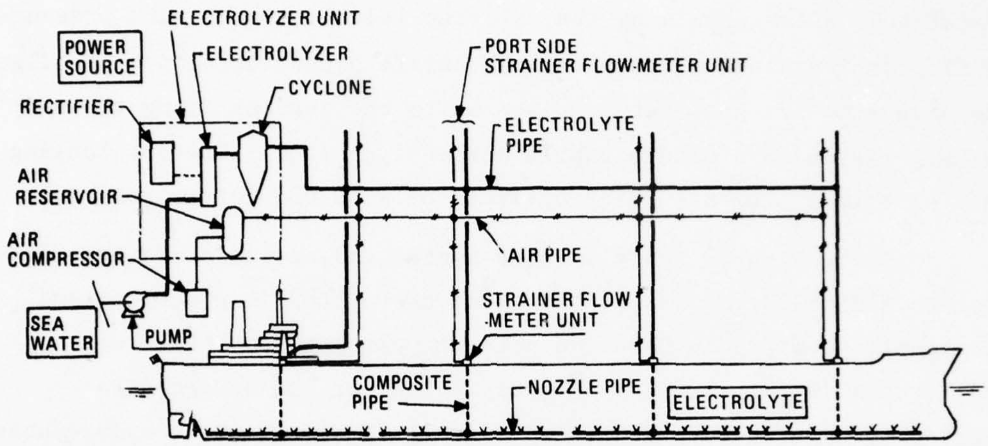


Figure B-7. Ship Installation, Electrolyzed Seawater System[21]

For compactness, the electrolyzer is built of a number of parallel spacing plate type electrodes. The cyclone separates the magnesium hydroxide and hydrogen gas, formed as by-products of electrolysis, to prevent choking the nozzles and to protect against gas explosion.

The nozzle pipe mixes the electrolyte and air, breaks up the mixture into minute bubbles, and distributes the electrolyte over the hull surface. Resistors are applied to the nozzles to provide uniform gas flow over the hull, that will remain unaffected by changes in the trim of the hull.

The electrolyzer unit, housed in a container having a capacity of about 3-1/2 cubic meters, is installed on the deck or in the upper part of the engine room. The container also houses rectifiers, electrolyzers, cyclones, an air tank, strainers, a switchboard, and various

B.3.6 Electrolyzed Seawater Hull Fouling Prevention System (Cont'd)

gauges. The electrolyzer unit treats the seawater and air supplied, respectively, by the seawater pump and air compressor installed in the lower part of the engine room, and feeds them into the main electrolyte and air pipes, respectively.

Due to the flexibility of the electrolyzers in which the chlorine concentration varies in proportion to the amperage, rectifiers with somewhat larger capacities than are normally needed could be designed. This would permit operation at a slightly higher concentration of electrolyte when the generator is working below its full capacity.

If an electrolyzer is actuated without seawater in it, not only will its insulators burn, but hydrogen and oxygen may also accumulate, causing fire and explosion. To prevent such dangers, the electrolyzers are so designed that they cannot be switched on unless the seawater pump is operating and there is a difference in pressure between their inlets and outlets.

The magnesium hydroxide is removed by the continuous blowing of about 10 percent of the underflow of the cyclone and separated with a smaller secondary cyclone. The gas passes through an antiexplosion filter, is adequately diluted, and then discharged by a ventilator fan.

Those portions of the inner surface of the electrolyzer unit which may come into contact with the electrolyte are lined with plastic or neoprene. As the whole unit is housed in a sturdy container, pipes and valves could be of hard vinyl chloride.

Double seawater strainers, with 16-mesh nets and slightly larger in diameter than the piping, are provided.

Table B-3 lists, as an example, the particulars of equipment and electric power consumption of principal units of the system for a 250,000-ton tanker. With one rectifier provided for each of the three electrolyzers, a sudden overload on the generator would automatically switch

B.3.6 Electrolyzed Seawater Hull Fouling Prevention System (Cont'd)

off one, two, or all three rectifiers when required, depending on the seriousness of the overload. They would then be switched on again automatically, when the overload on the generator is relieved.

TABLE B-3

PARTICULARS OF EQUIPMENTS AND POWER CONSUMPTION (250,000 DWT TANKER)

Item	No. of Units		Power Consumption
Rectifier	3	75 ∿ 150 V x 660A	126 kW
Electrolyzer	3	Platinum-coated titanium plate (pt. 1.5μ)	--
Seawater pump	1	280 m^3/h x 500 m TH.	54 kW
Air compressor	1	250 m^3/h (F.A.) x 7 kg/cm^2	28 kW
Air tank reservoir	1	800 1 x 7 kg/cm^2	--
Ventilator fan	1	10 m^3/min x 60 mm H_2O	0.6 kW
		Total	209 kW

The costs of system hardware and installation will depend on final system configurations.

These systems are far enough downstream for U.S. application that personnel, equipment support, and gaps in technology and environmental considerations are not currently obvious.

B.3.7 Aquatron Scale and Algae Elimination System[38]

B.3.7.1 State-of-the-Art. The Aquatron system developed by Delta Tech Corporation, Dothan, Alabama, was designed to electronically treat water to prevent earth salt scale from forming on water wall surfaces, to remove earth salt scale from these surfaces, and to kill microorganisms. It is anticipated that Aquatron can prevent slime films,

B.3.7 Aquatron Scale and Algae Elimination System (Cont'd)

which precede attachment of other marine fouling organisms, from forming in seawater systems. This system can be installed in any water circulation system.

The Aquatron system operates electronically, charging in water with 12.56 VDC potential across an anode and a cathode. The current flow range is normally measured in milliamps, varying with the level of totally dissolved solids (TDS) and water volume. 12.56 VDC is the exact ionization potential for water. This value was determined over one hundred years ago and is listed in most chemistry and physics handbooks. Ionization potential is the work (expressed in electron volts) required to remove a given electron from its atomic orbit and place it at rest at an infinite distance. Ionization of water occurs most readily at 12.56 VDC with no measurable increase in ionization achieved above this voltage. The effectiveness of ionization is retained for a period of some 14 to 15 hours.

Research has determined the effective designs of the activation chamber. In the activation chamber, the quantum level of the electrons is increased in the water molecule, allowing ionization to readily occur. The ionization produces an increased supply of both hydrogen ions (positive) and hydroxide ions (negative) in the solution. These ions act as a buffering agent, surrounding oppositely charged ions dissolved in the solution and preventing their precipitation or combination with other ions buffered by hydrogen ions or hydroxide ions. This reaction has long been known to interfere with chemical reactions in solution. Ionized water provides both of these ions, thus being effective in solutions of varying PH, and reacts with all totally dissolved solids.

The cause and effects of this ionization in various applications are listed below:

B.3.7 Aquatron Scale and Algae Elimination System (Cont'd)

a. Prevention of earth salt scale formation. In various water circulation systems such as boilers, chillers, equipment cooling systems, and water piping systems precipitation of earth salts on the water wall surfaces have historically been a technical problem faced by industry. Aquatron prevents formation of such scale on the water wall surfaces and heat exchange surfaces through the buffering effect of ionized water. The TDS is held in solution in ionized form surrounded by the hydrogen and hydroxide ions.

b. Removal of earth salt scale. The surface of earth salt exists in a semi-equilibrium state, exchanging ions with the solution at a rate dependent upon the level of solution saturation. As this exchange takes place, the released ions from the scale are captured by the buffering effects and held in solution. By this method, the scale is dissolved and removed. Ionized water also increases the level of TDS required to saturate water.

c. Killing of microbiological organisms. An ion exchange between microorganisms and water is necessary for the growth of the organisms. The buffering action of ionization of water prohibits this exchange, therefore starving the organisms.

d. Ionized water reacts like soft water. Some of the physical and chemical characteristics of this phenomenon are that the water acts as sequestrant, the surface tension is significantly reduced, and foaming is reduced in a boiler.

B.3.7 Aquatron Scale and Algae Elimination System (Cont'd)

Numerous applications of the Aquatron system are cited by Delta Tech Corporation. The installations thus far have been primarily in fresh and well water land-based systems. The descaling effect and the killing of algae has been spectacular, occuring in 3 to 4 week periods in most cases cited. A sampling of installations cited by Delta Tech Corporation were at the following companies:

- Union Carbide Battery Division, Charlotte, N.C.
- Craftsmen Fabrics Incorporated, Concord, N.C.
- C. Galvan Industries, Harrisburg, N.C.
- U. S. Marine Corps, Camp Lejune, N.C.

In 1974, Mr. John Yandell, developer of Aquatron Systems, set up a test to determine the feasibility of the system in seawater. The test was run with a small 1500 pound-per-hour fire tube boiler for two weeks. The unit successfully operated using seawater from the Atlantic Ocean and prevented scale formation on the heat exchange surfaces of the boiler. The extreme level of dissolved solids in the boiler from the seawater required a high rate of continuous blowdown to remain in operation; this blowdown reduced boiler capacity significantly as expected. Conclusions drawn were: (1) that Aquatron can operate successfully with seawater and (2) Aquatron can be used in emergency cases to steam Naval vessels back to port using seawater.

The advantages of electrolytic systems over electrostatic systems are as follows.

1. Aquatron which is an electrolytic system is not limited by heat exchange rates (BTU/Hr.) because the system utilizes buffering by ionization rather than polarization of water molecules.

B.3.7 Aquatron Scale and Algae Elimination System (Cont'd)

2. Aquatron can theoretically operate up to 1750 psi or to that point at which steam and water begin to become mixed. Ionization can occur as long as current can flow through the water. Therefore, a steam/water mixture found at the extreme pressures would prohibit this action.

3. Maintenance of the Aquatron system is a simple exchange of probes in the course of the preventive maintenance program. The design of the unit is constructed to withstand extreme operating conditions.

4. No deteriorating effects to ionization occur as the ionized water is passed through pumps or other mechanical devices which change the energy level in ionized water.

B.3.7.2 Technology Gaps.

1. Engineering is in the planning stage to evaluate ionized water action under high pressure, with a goal of 1200 psi. There are no known problems in the effects of ionization at this pressure.

2. Engineering design within Delta Tech Corporation is presently preparing for studies in extreme flow rate applications of 5000 GPM and above. The primary problem is the physical size of the system versus the layout of presently installed equipment.

3. Test and evaluation is required to determine proper application of ionized water to the skin of a naval vessel for prevention of fouling. Tests might also be performed to determine the effectiveness on improved ship speed when traveling through ionized water which

B.3.7 Aquatron Scale and Algae Elimination System (Cont'd)

has reduced surface tension. Note that the Aquatron system reduces the surface tension of water treated.

B.3.7.3 Needed RDT&E

1. A complete analysis of the effective application of ionized water systems for cleaning ship hulls is required. It is anticipated that Aquatron can prevent the slime film forming, which precedes attachment of larval macroorganisms. Further testing of this application is required.

2. Testing is required to verify that ionized water does not reflect any wave form change in radar cooling systems.

3. Corrosion tendencies in an ionized water environment should be evaluated.

B.3.7.4 Environmental Considerations. After approximately 14 hours, ionized water reverts back to its original state. Thus, after one-half day, effluent is indistinguishable from pure water. In normal boiler operations, water discharged in blowdown is the same chemically as the makeup water, except that the concentration of chemicals is slightly higher due to redissolving of precipitates. Some crystalline forms are noted as changing due to higher energy levels, although the chemical makeup is the same. No effect on the environment is discernable.

B.3.7.5 Personnel Considerations. Units are designed to be operated by monitoring devices with the following planned maintenance time required:

Daily - One man, E-4, 0.4 Man-hour
Weekly - One Man, E-4, 1 Man-hour
Monthly - Two Men, E-4, E-3, 4 Man-hours

B.3.7 Aquatron Scale and Algae Elimination System (Cont'd)

Training required for operation and maintenance is based on a two-day seminar and training manuals. The seminar can be held by E-7 personnel or equivalent. Skill required to maintain units is basic electronic skill. Repair work on units is done by module replacement well within the time allowed for monthly planned maintenance.

B.3.7.6 Equipment Support. The basic configuration of this system consists of: (1) the power supply, (2) the activation chamber, and (3) the replacement probes. The power supply is modulized for ease of repair and reportedly has a mean time between failure of over 200 days. Spare parts can be carried to support the unit for a two-year period. The activation chamber is constructed of standard materials easily repaired if structural damage occurs. The replacement probes are to be replaced on a planned basis and are to be stocked as low-cost spare parts which are standardized for universal bid spares design.

B.3.7.7 Effectiveness Evaluation Plan. The specific plan should be formulated after experimental evaluation of a proposed plan. The proposed plan would entail the following:

Make comparative evaluations of records of system parameters. Antifouling system performance degradation to an unacceptable level may be based upon such criteria as:

a. A 10 percent drop in efficiency of heat transfer units

b. A 10 percent increase in pressure drop across system components

c. Visual accumulation of fouling in the sea chests

A video-audio tape and hard copy documentation record bank would provide the means of avoiding subjective judgments. A criterion for an unacceptable amount of corrosion would have to be developed.

B.3.7 Aquatron Scale and Algae Elimination System (Cont'd)

B.3.7.8 Development Progress Tracking Plan. The development progress tracking plan is seen to fall within the total context of the general plan described in Paragraph B.2.2.3. All elements of the tracking effort would be specifically related to the development of the Aquatron system described above.

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ANNEX B-I

OPNAVINST 6240.3D POLICY AND RESPONSIBILITIES

POLICY AND RESPONSIBILITIES

Part 1

DISCUSSION AND POLICY

1101. Purpose

The purpose of this chapter is to promulgate policy, assign responsibilities, and to prescribe Navy-wide actions for the protection of the environment and conservation of natural resources.

1102. Discussion

a. Continued emphasis and direction related to combating environmental pollution by Federal agencies have been demonstrated by Presidential Executive Orders and Congressional legislation. All facilities owned by, or leased to, the Federal Government must be designed, operated, maintained and monitored to conform to applicable air, water, and noise standards established by Federal, state, and local authorities. Executive Orders 11514 and 11752 emphasize the role of the Federal Government and its agencies in providing leadership in the nation-wide effort to protect and enhance the quality of our environment.

b. The policies of the Department of Defense regarding the development and submission of plans for installing improvements needed to abate air, water and noise pollution emanating from DoD facilities and the issuance of references implementing these policies are promulgated in DOD Instruction 4120.14.

c. The National Environmental Policy Act is one of the most all-encompassing laws passed in this decade. It requires Federal agencies to build into the mainstream of their decision-making, down to every level of organization, an awareness of environmental factors at the very inception of the formulation of plans and programs. Any major Federal action that may have a significant impact on the quality of human environment, or that may be highly controversial in environmental effects, requires the filing of an Environmental Impact Statement (EIS) with the President's Council on Environmental Quality (CEQ). Therefore, in implementing procedures and assigning responsibilities within the Navy, this manual covers, in detail, the preparation and processing of Environmental Impact Statements.

1103. Policy

a. The Navy will actively participate in a program to protect and enhance the quality of the environment, through adherence to all applicable regulatory standards, and by initiating actions to conserve natural resources, protect historical and cultural properties and prevent or control pollution caused by Navy facilities.

b. In accordance with E.O. 11752, Navy shore activities and forces afloat, as appropriate, will cooperate with Federal, state, and local environmental protection organizations and comply with the official substantive standards and criteria promulgated by such agencies. However, it is not required that naval facilities comply with state or local administrative procedures with respect to pollution abatement and control. Where, in the interest of national defense or other relevant reasons, it is considered impracticable to comply with such standards and criteria, the matter should be referred to the Chief of Naval Operations (Op-04) via the chain of command, for resolution.

c. The Navy will establish an integrated multiple-use program for the renewable natural resources in forests and woodlands, fish and wildlife, soil, water, grasslands, outdoor recreation, landscaping, natural beauty, protection of endangered species and preservation of cultural and historic properties in consonance with federal programs and compatible with the military mission.

d. It is Navy policy that Navy installations overseas will cooperate with the host country in implementing Navy environmental programs to the extent practicable and conform at all times to the environmental quality standards of the host country, international agreements and status of forces agreements.

e. Navy ships in foreign harbors and units overseas will conform to environmental quality standards set forth in applicable international, bilateral and status of forces agreements to which the U.S. Government is a party.

f. The Navy shall insure that policies and procedures for the prevention, control and abatement of air, water, and noise pollution comply with E.O.'s 11514 and 11752.

g. Where resources to accomplish pollution control are limited, priority of effort will be afforded in accordance with the following order: (1) those situations which constitute a direct hazard to the health of man; (2) those having economic implications; and (3) those which affect the recreational and esthetic value of our natural resources.

h. RDT&E efforts and engineering investigations shall be initiated, when required, for Navy environmental pollution problems to meet existing pollution abatement standards and anticipated standards for national policy regarding pollution. RDT&E studies utilizing Navy funds should be directed towards solving specific Navy-caused pollution problems. Broad studies for improvement or surveillance of non-Navy environmental problems should normally be funded by the Federal agency that has primary responsibility for the effort.

i. Environmental pollution controls, procedures, methods, and systems shall be coordinated with standards promulgated pursuant to the Occupational Safety and Health Act, as amended, and related Navy directives, in order to insure safe and healthful work conditions for naval personnel.

j. Cost-effectiveness studies shall be conducted, as applicable, prior to making a decision among options for meeting environmental quality standards. For example, in some cases it may be more efficient or effective to phase out and transfer activities to other activities, rather than install pollution control devices. In other instances, it may prove more economical to install new equipment or systems rather than control existing systems. Where alternatives such as construction of new waste treatment systems or connection to municipal systems, particularly regional systems, are available, the alternatives will be analyzed and evaluated as required by regulations on the economics of proposed DOD investments as well as for environmental considerations.

k. Executive Order 11752 provides that Heads of agencies shall not use for any other purpose any of the amounts appropriated and apportioned for pollution abatement projects necessary to meet the requirements of the Executive Order. Accordingly, all funds appropriated and apportioned for pollution abatement projects under the Navy Environmental Protection Program shall not be used for any other purposes.

l. Environmental pollution prevention features will be incorporated in the basic design and requests for funding for weapons systems, naval vessels, aircraft, logistic systems and materials, tests and exercises, and projects for conversion, alteration, expansion, extension and construction of facilities. The preferred method for abatement and control of environmental pollution is at the source of the pollutants. Therefore, environmental pollution prevention shall be integrated into any planned industrial process, operation, or product and be considered as part of the cost of daily operations.

m. Insofar as feasible, the Navy shall participate in regional community pollution abatement systems and shall purchase services from such systems in lieu of constructing and operating such facilities.

n. The use, storage, and handling of all materials, including, but not limited to, solid fuels, ashes, petroleum products, and other chemical and biological agents, shall be carried out to avoid or minimize the possibilities of water and air pollution. When appropriate, preventive measures shall be taken to entrap spillage or discharge to prevent accidental pollution. Each command and activity shall establish appropriate emergency plans and procedures for dealing with accidental pollution.

o. No waste shall be disposed of or discharged in any manner which could result in the pollution of ground water and endanger the health or welfare of the public.

p. Discharges of radioactive materials shall be in accordance with the applicable rules, regulations, or requirements of the Energy Research and Development Administration or the Nuclear Regulatory Commission, as appropriate, and with the policies and guidance of the Environmental Protection Agency as published in the Federal Register.

q. Under applicable Federal laws and EPA regulations, no Federal agency shall enter into any contract for the procurement of goods, materials or services, to be performed in whole or in part, in a facility which has given rise to a conviction of an offense in violation of a Federal environmental law.

r. The transportation and discharge to the sea, or any waters, of oils, oily wastes, sludges, industrial wastes, or refuse, that have been collected ashore or from ships in port is prohibited. The disposal of unserviceable ammunition to the sea is also prohibited except as may be specifically authorized on a case-by-case basis by the Chief of Naval Operations and in accordance with appropriate EPA ocean dumping regulations (40 CFR 220-227).

s. Each Navy command operating a waste collection or treatment system shall have positive control over the wastes which are delivered to that system for transportation and/or processing. As appropriate, intra-base procedures for such control shall be established, as for example, in host/tenant agreements and in inter-service support agreements.

t. Pollution abatement funds shall not be used for recurring operation or maintenance costs nor will they be used to fund costs of pollution control aspects of new facilities or modifications or alterations.

Part 2

RESPONSIBILITIES

1201. Office of the Chief of Naval Operations

a. Within OPNAV the Deputy Chief of Naval Operations (Logistics) or his designee shall:

(1) Have responsibility for establishing policy, directing, coordinating, and monitoring the environmental protection program within the Navy.

(2) Assure effective coordination with the Assistant Secretary of Defense (Health and Environment), the Assistant Secretary of Defense (Installations and Logistics) and with non-DOD agencies involved in environmental quality matters.

(3) Provide Navy focal point for review of environmental impact statements.

b. Deputy Chiefs (DCNO's) and Directors of Major Staff Offices (DMSO's) of Naval Operations shall:

(1) Take continuing actions for the furtherance of environmental quality to include establishing requirements and priorities within their respective areas of

cognizance, in accordance with their missions and functions assigned in the Chief of Naval Operations (OPNAV) Organization Manual.

(2) As Program Sponsors, make provisions in their respective plans, programs, and budgets for attaining environmental quality and management of natural resources consistent with the provisions of this instruction.

c. The Chief of Information (CHINFO) shall coordinate and supervise the release of information concerning environmental quality matters to the public media. CHINFO will also, on request, provide guidance on the conduct of environmental public affairs efforts which might be considered complex and/or sensitive.

1202. The Chief of Naval Material

The Chief of Naval Material shall, in accordance with the broad requirements and priorities established by the Chief of Naval Operations:

a. Identify and evaluate on a continuing basis, naval systems and equipments affecting environmental quality, including but not limited to air and water pollution, solid waste management and disposal practices, noise, sources of thermal energy, ionizing and non-ionizing radiation, chemical agents, and biological research materials.

b. Validate all material-related facility projects and programs to correct environmental deficiencies prior to their inclusion in the Office of Management and Budget reports as promulgated by DODINST 4120.14 and in accordance with applicable instructions.

c. Perform research to define and study environmental pollution problems associated with the fulfillment of naval material development and acquisition requirements, including those requirements associated with weapons systems, ensuring that consideration is given to the control of environmental pollution through research, development, test and evaluation of such systems. Coordinate such research actions with other Navy commands, other Department of Defense components and Federal agencies.

d. Identify and develop, in coordination with appropriate commands, manpower and material requirements in support of the environmental protection program.

e. Ensure that environmental quality problems associated with the use and production of new materials are recognized and programs are established for their control, abatement and eventual disposal.

f. When required, provide technical advice concerning the probable consequences affecting the quality of the environment of Navy facilities and operations. Provide technical advice and assistance to other naval offices and commands on environmental quality matters under the cognizance of the Naval Material Command.

g. Establish and maintain, in support of the Naval District Commandants and other commanders and commanding officers, a focal point of contact at each Engineering Field Division (EFD) of the Naval Facilities Engineering Command, for the purpose of providing technical assistance and coordination in carrying out the requirements of this instruction, and ensuring development and maintenance of a common Navy position with respect to compliance with applicable state, interstate, and local requirements for the control and abatement of environmental pollution. Coordination and technical assistance in this respect shall be accomplished with due regard to governing regulations (Navy Regulations, Article 0765), which place primary responsibility for cooperation and coordination with state and local pollution control agencies on the individual commanding officer. In view of the absolute necessity for maintaining a consistent and uniform position throughout the Navy with respect to compliance with state, interstate, and local pollution control requirements, it is emphasized that maximum communication and cooperation between individual commanders/commanding officers and the cognizant EFD is essential. Implementing instructions are to ensure that advance clearance with NAVSEASYSCOMHQ (08) is made for any visit which could include discussions concerning shipboard related radioactive waste associated with U.S. nuclear propulsion plants and their supporting tenders, bases, and shipyards.

h. Ensure that all matters concerning those aspects of environmental pollution control which relate to the control of radioactivity associated with naval nuclear propulsion plants and their support facilities are referred to NAVSEASYSCOM (08) for action or comment, as appropriate.

i. Operate the Naval Environmental Protection Support Service (NEPSS) program which has the function of providing support to naval activities with respect to environmental data collection and monitoring. This service is intended to determine the extent to which the environment is affected by naval facilities and assist all elements of the Navy to comply with Navy, Federal, state and local environmental quality standards.

1203. <u>The Chief, Bureau of Medicine and Surgery</u>

The Chief, Bureau of Medicine and Surgery shall:

a. Determine, validate, and establish health criteria and standards.

b. Provide occupational environmental health program coordination in the office of the Chief of Naval Operations (Op-45 and Op-09F) to assure that measures to meet environmental protection standards are compatible with health and safety standards.

c. Identify and evaluate, on a continuing basis, naval systems, equipments, procedures and facilities affecting environmental quality, assuring that health problems are recognized and programs of corrective action recommended.

d. Maintain Navy Regional Medical Center (NAVREGMEDCEN) occupational health program interface with NAVFAC Engineering Field Division environmental protection program, and promote the close coordination of both programs to ensure that health and environmental protection standards are appropriately considered and in accord at field level.

e. Participate in all planning and programming actions to assure that full and appropriate consideration is given to personnel health in the development of naval systems, material, and facilities.

f. As required, provide technical advice and assistance to other naval offices, bureaus, and commands concerning the health aspects of Naval environments.

g. Perform research in environmental medicine and environmental toxicology to determine the health and environmental impacts of unique Navy pollutants.

h. As required, provide assistance to the Naval Environmental Protection Support Service in environmental monitoring and data collection related to health problems.

i. Collect, collate, and disseminate, in coordination with the Naval Environmental Protection Support Service (NEPSS), technical data related to health problems associated with specific sources of environmental pollution and environmental pollution control systems.

1204. The Chief of Naval Education and Training

The Chief of Naval Education and Training shall direct the establishment of training programs for naval personnel in furtherance of the foregoing program policy, and as necessary assist other offices and commands in meeting the responsibilities stated herein.

1205. Area Coordinators

Area Coordinators shall coordinate and implement the National Oil and Hazardous Substances Pollution Contingency Plan (40 CFR 1510), within their respective areas; promote environmental protection and enhancement efforts being conducted under the primary responsibility of subordinate and other commands; and coordinate and foster public release of information on environmental quality matters.

1206. The Oceanographer of the Navy

The Oceanographer of the Navy shall:

a. Assist the CNO in identifying and conducting those research, survey and investigative activities necessary to assess the impact of naval operations and Navy generated waste upon the marine environment.

b. Validate and comment upon adequacy of proposed Navy sponsored investigations related to marine environmental quality.

c. Serve as the focal point within Navy for coordinating and/or conducting field investigations in the marine environment related to ocean dumping.

d. Provide oceanographic data and technical support to those commands investigating the marine environmental impact of new systems, equipments and procedures.

e. In consonance with the NEPSS, provide Navy an information source of Navy sponsored research related to marine environmental quality.

1207. The Commander, Naval Weather Service Command

The Commander of the Naval Weather Service Command shall provide meteorological/oceanographic forecasts as required, to support Navy pollution control measures. The Naval Weather Service shall forecast atmospheric phenomena affecting dispersal of airborne emissions and reports to on-scene coordinators for movement predictions of reported oil slicks at sea.

1208. Major Claimants and Subordinate Commands

Due to the important role of major claimants in the planning, programming, budgeting and execution cycle, major claimants are principally responsible for adequate environmental quality and natural resources management programs. Major claimants and subordinate commands shall be responsible for identifying and maintaining current information concerning all aspects of their operations significantly affecting environmental quality, and shall determine the feasibility of taking any necessary actions to improve environmental quality. A focal point for environmental matters shall be established in each major claimant, with the responsibility of coordinating all internal Navy actions and programs, in his area of interest, that affect the environment as delineated in this instruction. Pursuant to governing regulations (Navy Regulations, Article 0765), and in furtherance of paragraph 1202.g., commanding officers bear primary responsibility for coordination and cooperation with Federal, state, interstate and local pollution control agencies with respect to control and abatement of environmental pollution. To ensure proper coordination and to maintain a focal point of technical expertise for assistance and support of major claimants and other commands, each command will coordinate environmental matters relating to Federal, state, interstate, and local pollution control agencies, with the cognizant Engineering Field Division of the Naval Facilities Engineering Command, in accordance with paragraph 1202.g.

1209. General

It is incumbent upon all Navy personnel, military and civilian, to become more innovative and imaginative in finding ways to reduce pollution of our land, air and water. Moreover, some long accepted and routine procedures and practices, although technically legal, may impact the environment and become subjected to external scrutiny and criticism. It is necessary to periodically review practices which may affect the environment and study whether measures can be taken to lessen or eliminate undesirable effects. Actions which do not significantly affect the environment may at times be construed by the public as harmful. In these cases, the Navy must ensure that the facts in each action are made clear to all interested persons, including as appropriate, the general public.

ANNEX B-II

CONDENSATION OF SIGNIFICANT ASPECTS AND EXCERPTS FROM THE FEDERAL REGISTER, VOLUME 40, NO. 250, PART IV "HAZARDOUS SUBSTANCES"

CONDENSATION OF SIGNIFICANT ASPECTS AND
EXCERPTS FROM THE FEDERAL REGISTER, VOLUME 40, NO. 250, PART IV
"HAZARDOUS SUBSTANCES"

I. DESIGNATION

Toxicological Selection Criteria[3]

Tentative selection criteria set forth in the August 22, 1974, Advance Notice were as follows:

1. Any element or compound produced in excess of research quantities possess sufficient danger potential to be considered as a candidate hazardous substance if it is lethal to: (a) One-half of a test population of aquatic animals in 96 hours or less at a concentration of 500 milligrams per liter (mg/l) or less; or (b) one-half of a test population of animals in 14 days or less when administered as a single oral dose equal to or less than 50 milligrams per kilogram (mg/kg) of body weight; or (c) one-half of a test population of animals in 14 days or less when dermally exposed to an amount equal to or less than 200 mg/kg body weight for 24 hours; or (d) one-half of a test population of animals in 14 days or less when exposed to a vapor concentration equal to or less than 200 cubic centimeters per cubic meter (volume/volume) in air for one hour; or (e) aquatic flora as measured by a 50 percent decrease in cell count, biomass, or photosynthetic ability in 14 days or less at concentrations equal to or less than 100 mg/l.

2. To be further considered for designation as a hazardous substance, any element or compound meeting the above criteria must have a reasonable potential for being discharged; i.e., spilled into a water body. Factors being considered in making this evaluation include the production quantities, modes of

transportation, handling and storing practices, past spill experience, and physical/chemical properties of each substance.

APPLICABILITY

The regulation of this part designates hazardous substances under Section 311(b)(2)(A) of the Act.* The proposed regulation applies to discharges of substances designated herein into navigable water or adjoining shorelines or the waters of the contiguous zone from vessels and onshore and offshore facilities.

"Vessel" means every description of watercraft or other artifical contrivance used, or capable of being used, as a means of transportation on water other than a public vessel.

LIST OF HAZARDOUS SUBSTANCES

The list of hazardous substances include pure substances and compounds which are considered hazardous in solid, liquid or gaseous form. The listed substances are designated as hazardous on the basis of toxicological properties of one component ion or group. The toxicological criteria met by each substance are denoted by the number on the left of the common name according to the following key:

1 = aquatic animal toxicity
2 = oral mammalian toxicity
3 = dermal mammalian toxicity
4 = inhalation mammalian toxicity
5 = phytotoxicity

The underlined headings in the list are provided only for ease of referencing and are not designated hazardous substances; e.g., Fluorine compounds does not mean that all fluorine compounds are designated as hazardous substances.

*Federal Water Polution Control Act.

	COMMON NAME	SYNONYMS	ISOMERS
1	Acetaldehyde	ethanal ethyl aldehyde aldehyde acetic aldehyde	
1	Acetic acid	glacial acetic acid vinegar acid	
1	Acetic anhydride	acetic oxide acetyl oxide	
2	Acetone cyanohydrin	2-methyllactonitrile alpha-hydroxyisobutyronitrile	
1	Acetyl bromide		
1	Acetyl chloride		
1, 2	Acrolein	2-propenal acrylic aldehyde acrylaldehyde acraldehyde	
1	Acrylonitrile	cyanoethylene Fumigrain Ventox propenenitrile vinyl cyanide	
2	Adiponitrile	1, 4-dicyanobutane	
1	Aldrin	Octalene HHDN	
1	Allyl alcohol	2-propen-1-ol 1-propenol-3 vinyl carbinol	
1	Allyl chloride	3-chloropropene 3-chloropropylene Chlorallylene	
1	Aluminum sulfate	alum	
1	Ammonia		

	COMMON NAME	SYNONYMS	ISOMERS
	Ammonium compounds		
1	Ammonium acetate	acetic acid ammonium salt	
1	Ammonium benzoate		
1	Ammonium bicarbonate	acid ammonium carbonate ammonium hydrogen carbonate	
1	Ammonium bisulfite		
1	Ammonium bromide		
1	Ammonium carbamate	ammonium aminoformate	
1	Ammonium carbonate		
1	Ammonium chloride	ammonium muriate sal ammoniac salmiac Amchlor	
1	Ammonium citrate, dibasic	diammonium citrate citric acid diammonium salt	
1	Ammonium fluoborate		
1	Ammonium hydroxide		
1	Ammonium hypophosphite		
1	Ammonium iodide		
1	Ammonium nitrate		
1	Ammonium oxalate		
1	Ammonium pentaborate	ammonium decaborate	
1	Ammonium persulfate	ammonium peroxydisulfate	
1	Ammonium silicofluoride	ammonium fluosilicate	
1	Ammonium sulfamate	Ammate AMS ammonium amidosulfate	
1	Ammonium sulfide		
1	Ammonium sulfite		
1	Ammonium tartrate	tartaric acid ammonium salt	
1	Ammonium thiocyanate	ammonium rhodanide ammonium sulfocyanate ammonium sulfocyanide	
1	Ammonium thiosulfate	ammonium hyposulfite	
1	Amyl acetate	amylacetic ester pear oil banana oil	normal-; iso-; secondary-; tertiary- amyl acetate
1	Aniline	aniline oil phenylamine aminobenzene aminophen kyanol	

	COMMON NAME	SYNONYMS	ISOMERS
	Antimony compounds		
1	Antimony pentachloride		
1	Antimony pentafluoride		
1	Antimony potassium tartrate	tartar emetic tartrated antimony tartarized antimony potassium antimonyltartrate	
1	Antimony tribromide		
1	Antimony trichloride	butter of antimony	
1	Antimony trifluoride	antimony fluoride	
1	Antimony trioxide	diantimony trioxide flowers of antimony	
	Arsenic compounds		
1, 3	Arsenic acid	orthoarsenic acid	
1	Arsenic disulfide	arsenic monosulfide red arsenic sulfide	
1, 2	Arsenic pentaoxide	arsenic acid anhydride arsenic oxide	
1	Arsenic trichloride	arsenic chloride arsenious chloride arsenous chloride butter of arsenic	
1, 2	Arsenic trioxide	arsenious acid arsenious oxide white arsenic	
1	Arsenic trisulfide	arsenious sulfide yellow arsenic sulfide	
1	Calcium arsenate	tricalcium ortho-arsenate	
1	Calcium arsenite		
1	Potassium arsenate		
1	Potassium arsenite	potassium metaarsenite	
1	Sodium arsenate	disodium arsenate	
1, 2	Sodium arsenite	sodium metaarsenite	
1	Benzene	cyclohexatriene benzol	
1	Benzoic acid	benzenecarboxylic acid phenylformic acid dracylic acid	
1, 3	Benzonitrile	phenyl cyanide cyanobenzene	
1	Benzoyl chloride	benzenecarbonyl chloride	
1	Benzyl chloride		

	COMMON NAME	SYNONYMS	ISOMERS
	Beryllium compounds		
1	Beryllium chloride		
1, 2	Beryllium fluoride		
1, 3	Beryllium nitrate		
1, 2	Butyl acetate	acetic acid normal- butyl ester acetic acid secondary- butyl ester acetic acid iso-butyl ester acetic acid tertiary-butyl ester	normal-; secondary-; iso-; tertiary- butyl acetate
1	Butylamine	1-; 2-aminobutane 2-amino-2-methylpropane 1-amino-2-methylpropane	normal-; secondary-; tertiary- butylamine
1	Butyric acid	butanoic acid ethylacetic acid	normal-; iso- butyric acid
	Cadmium compounds		
1	Cadmium acetate		
1	Cadmium bromide		
1	Cadmium chloride		
1	Calcium carbide	carbide acetylenogen	
1	Calcium hydroxide	lime, hydrated slaked lime calcium hydrate	
1	Calcium hypochlorite		
1	Calcium oxide	lime quicklime	
1, 2	Captan	Orthocide-406 SR-406 Vancide-89	
1	Carbaryl	Sevin	
1	Carbon disulfide	carbon bisulfide dithiocarbonic anhydride	
1	Chlordane	Toxichlor	
1	Chlorine		

	COMMON NAME	SYNONYMS	ISOMERS
1	Chlorobenzene	monochlorobenzene	
		benzene chloride	
1	Chloroform	trichloromethane	
1	Chlorosulfonic acid	sulfuric chlorohydrin	
	Chromium compounds		
1	Ammonium bichromate	ammonium dichromate	
1	Ammonium chromate		
1, 2	Calcium chromate	calcium chrome yellow	
		gelbin	
		yellow ultramarine	
3	Chromic acetate		
1	Chromic acid	chromic anhydride	
		chromium trioxide	
1	Chromic sulfate		
1	Chromous chloride		
1	Chromyl chloride	chromium dioxychloride	
1	Lithium bichromate	lithium dichromate	
1	Lithium chromate		
1	Potassium bichromate	potassium dichromate	
1	Potassium chromate		
1	Sodium bichromate	sodium dichromate	
1	Sodium chromate		
1	Strontium chromate		
1	Zinc bichromate	zinc dichromate	
	Cobalt compounds		
1	Cobaltous bromide	cobalt bromide	
1	Cobaltous fluoride	cobalt fluoride	
1	Cobaltous formate	cobalt formate	
1	Cobaltous sulfamate	cobalt sulfamate	
	Copper compounds		
1	Cupric acetate	copper acetate	
		crystallized verdigris	
1, 2	Cupric acetoarsenite	copper acetoarsenite	
		copper acetate arsenite	
		Paris green	
1	Cupric chloride	copper chloride	
1	Cupric formate	copper formate	
1	Cupric glycinate	copper glycinate	
		cupric aminoacetate	
1	Cupric lactate	copper lactate	
1	Cupric nitrate	copper nitrate	
1	Cupric oxalate	copper oxalate	
1	Cupric subacetate	basic copper acetate	
1	Cupric sulfate	copper sulfate	
1	Cupric sulfate, ammoniated	ammoniated copper sulfate	

	COMMON NAME	SYNONYMS	ISOMERS
1	Cupric tartrate	copper tartrate	
1	Cuprous bromide	copper bromide	
1, 2	Coumaphos	Co-Ral	
1	Cresol	cresylic acid	meta-;ortho-;
		hydroxytoluene	para-cresol
	Cyanide compounds		
1	Barium cyanide		
1	Calcium cyanide		
1, 2	Hydrogen cyanide	hydrocyanic acid	
1, 2	Potassium cyanide		
1, 2	Sodium cyanide		
1	Zinc cyanide		
1	Cyanogen chloride		
1	Cyclohexane	hexahydrobenzene	
		hexamethylene	
		hexanaphthene	
1	2, 4-D (acid)	2, 4-dichlorophenoxyacetic acid	
1	2, 4-D (esters)	2, 4-dichlorophenoxyacetic acid esters	
1	Dalapon	Dowpon	
		Gramevin	
		Radapon	
		Unipon	
1	DDT	p, p'-DDT	
1	Diazinon	Dipofene	
		Diazitol	
		Basudin	
		Spectracide	
1	Dicamba	2-methoxy-3, 6-dichlorobenzoic acid	
1	Dichlobenil	2, 6-dichlorobenzonitrile	
		2, 6-DBN	
1	Dichlone	Phygon	
		dichloronaphthoquinone	
1	Dichlorvos	2, 2-dichlorovinyl dimethyl phosphate	
		Vapona	
1	Dieldrin	Alvit	
1	Diethylamine		

	COMMON NAME	SYNONYMS	ISOMERS
1	Dimethylamine		
1	Dinitrobenzene	dinitrobenzol	
1, 2	Dinitrophenol	Aldifen	2, 3-;2, 4-; 2, 5-;2, 6; 3, 4-; 3, 5- dinitrophenol
1	Diquat	Aquacide Dextrone Reglone Diquat dibromide	
1, 2	Disulfoton	Di-syston	
1	Diuron	DCMU DMU	
1	Dodecylbenzenesulfonic acid		
1	Dodecylbenzenesulfonic acid, calcium salt		
1	Dodecylbenzenesulfonic acid, isopropanolamine salt		
1	Dodecylbenzenesulfonic acid, sodium salt		
1	Dodecylbenzenesulfonic acid, triethanolamine salt		
1	Dursban	chlorpyrifos	
1	Endosulfan	Thiodan	
1, 2	Endrin	Mendrin Compound 269	
1, 2	Ethion	Nialate	
1	Ethylbenzene		
1	Ethylenediamine	1, 2-diaminoethane	
1	Ethylenediamine-tetraacetic acid	EDTA edetic acid Havidote (ethylenedinitrilo)-tetraacetic acid	
	Fluorine compounds		
1	Aluminum fluoride	aluminum trifluoride	
1	Ammonium bifluoride	acid ammonium fluoride ammonium hydrogen fluoride	
1, 2	Ammonium fluoride	neutral ammonium fluoride	
1	Hydrofluoric acid	fluohydric acid	
1	Sodium bifluoride		
1	Sodium fluoride	villiaumite	
1	Stannous fluoride		

	COMMON NAME	SYNONYMS	ISOMERS
1	Formaldehyde	methyl aldehyde methanal formalin	
1	Formic acid	methanoic acid	
1	Fumaric acid	trans-butenedioic acid trans-1, 2-ethylene-dicarboxylic acid boletic acid allomaleic acid	
1	Furfural	2-furaldehyde pyromucic aldehyde	
1, 2	Guthion	Gusathion azinphos-methyl	
1	Heptachlor	Velsicol-104 Drinox Heptagran	
1	Hydrochloric acid	hydrogen chloride muriatic acid	
1	Hydroxylamine	oxammonium	
	Iron compounds		
1	Ferric ammonium citrate	ammonium ferric citrate	
1	Ferric ammonium oxalate	ammonium ferric oxalate	
1	Ferric chloride	flores martis iron trichloride	
1	Ferric fluoride		
1	Ferric nitrate	iron nitrate	
1	Ferric sulfate	ferric persulfate ferric sesquisulfate ferric tersulfate	
1	Ferrous ammonium sulfate	Mohr's salt iron ammonium sulfate	
1	Ferrous chloride	iron chloride iron dichloride iron protochloride	
1	Ferrous sulfate	green vitriol iron vitriol iron sulfate iron protosulfate	
1	Isoprene	2-methyl-1, 3-butadiene	
1	Kelthane	di(p-chlorophenyl)-trichloromethylcarbinol DTMC dicofol	

	COMMON NAME	SYNONYMS	ISOMERS
	<u>Lead compounds</u>		
1	Lead acetate	sugar of lead	
1	Lead arsenate		
1	Lead chloride		
1	Lead fluoborate		
1	Lead fluoride	lead difluoride plumbous fluoride	
1	Lead iodide		
1	Lead nitrate		
1	Lead stearate	stearic acid lead salt	
1	Lead sulfate		
1	Lead sulfide	galena	
1	Lead tetraacetate		
1	Lead thiocyanate	lead sulfocyanate	
1	Lead thiosulfate		
1	Lead tungstate		
1	Lindane	gamma-BHC gamma-benzene hexachloride	
1	Malathion	phosphothion	
1	Maleic acid	cis-butenedioic acid cis-1, 2-ethylenedicarboxylic acid toxilic acid	
1	Maleic anhydride	2, 5-furandione cis-butenedioic anhydride toxilic anhydride	
	<u>Mercury compounds</u>		
1	Mercuric acetate	mercury acetate	
1	Mercuric cyanide	mercury cyanide	
1	Mercuric nitrate	mercury nitrate mercury pernitrate	
1	Mercuric sulfate	mercury sulfate mercury persulfate mercury bisulfate	
1	Mercuric thiocyanate	mercury thiocyanate mercuric sulfocyanate mercuric sulfocyanide	
1	Mercurous nitrate	mercury protonitrate	
1	Methoxychlor	DMDT methoxy-DDT	
1	Methyl mercaptan	methanethiol mercaptomethane methyl sulfhydrate thiomethyl alcohol	

	COMMON NAME	SYNONYMS	ISOMERS
1	Methyl methacrylate	methacrylic acid methyl ester methyl-2-methyl-2-propenoate	
1, 2	Methyl parathion	Nitrox-80	
1, 2	Mevinphos	Phosdrin	
1	Monoethylamine	ethylamine aminoethane	
1	Monomethylamine	methylamine aminomethane	
1	Naled	Dibrom	
1	Naphthalene	white tar tar camphor naphthalin	
1	Naphthenic acid	cyclohexanecarboxylic acid hexahydrobenzoic acid	
	<u>Nickel compounds</u>		
1	Nickel ammonium sulfate	ammonium nickel sulfate	
1, 2	Nickel chloride	nickelous chloride	
1	Nickel formate		
1	Nickel hydroxide	nickelous hydroxide	
1	Nickel nitrate		
1	Nickel sulfate	nickelous sulfate	
1	Nitric acid	aqua fortis	
1	Nitrobenzene	nitrobenzol oil of mirbane	
1	Nitrogen dioxide	nitrogen tetraoxide	
1	Nitrophenol	mononitrophenol	meta-; ortho-; para- nitrophenol
1	Paraformaldehyde	Paraform Formagene Triformol polymerized formaldehyde polyoxymethylene	
1, 2	Parathion	DNTP Niran	

	COMMON NAME	SYNONYMS	ISOMERS
1	**Pentachlorophenol**	PCP Penta	
1	**Phenol**	carbolic acid phenyl hydroxide hydroxybenzene oxybenzene	
1	**Phosgene**	diphosgene carbonyl chloride chloroformyl chloride	
1	**Phosphoric acid**	orthophosphoric acid	
1, 2	**Phosphorus**	black phosphorus red phosphorus white phosphorus yellow phosphorus	
1	**Phosphorus oxychloride**	phosphoryl chloride phosphorus chloride	
1	**Phosphorus pentasulfide**	phosphoric sulfide thiophosphoric anhydride phosphorus persulfide	
1	**Phosphorus trichloride**	phosphorous chloride	
1	**Polychlorinated biphenyls**	PCB Aroclor Polychlorinated diphenyls	
1	Potassium hydroxide	potassium hydrate caustic potash potassa	
1	Potassium permanganate	chameleon mineral	
1	Propionic acid	propanoic acid methylacetic acid ethylformic acid	
1	Propionic anhydride	propanoic anhydride methylacetic anhydride	
1	Propyl alcohol	ethyl carbinol propylic alcohol propanol	normal-; iso-propyl alcohol
1	Pyrethrins	Pyrethrin I Pyrethrin II	

	COMMON NAME	SYNONYMS	ISOMERS
1	Quinoline	1-benzazine benzo[b]pyridine leucoline chinoleine leucol	
1	Resorcinol	resorcin 1, 3-benzenediol meta-dihydroxybenzene	
	Selenium compounds		
1	Selenium oxide	selenium dioxide	
1, 2	Sodium selenite		
1	Sodium	natrium	
1	Sodium bisulfite	sodium acid sulfite sodium hydrogen sulfite	
1	Sodium hydrosulfide	sodium sulfhydrate	
1	Sodium hydroxide	caustic soda soda lye sodium hydrate	
1	Sodium hypochlorite	bleach	
1	Sodium methylate	sodium methoxide	
1	Sodium nitrite		
1	Sodium phosphate, dibasic		
1	Sodium phosphate, monobasic		
1	Sodium phosphate, tribasic		
1	Sodium sulfide		
1, 2	Strychnine		
1	Styrene	vinylbenzene phenylethylene styrol styrolene cinnamene cinnamol	
1	Sulfuric acid	oil of vitriol oleum	
1	Sulfur monochloride	sulfur chloride	

	COMMON NAME	SYNONYMS	ISOMERS
1	2,4,5-T (acid)	2,4,5-trichlorophenoxyacetic acid	
1	2,4,5-T (esters)	2,4,5-trichlorophenoxyacetic esters	
1	TDE	DDD	
1	Tetraethyl lead	lead tetraethyl TEL	
1,2	Tetraethyl pyrophosphate	TEPP	
1	Toluene	toluol methylbenzene phenylmethane Methacide	
1	Toxaphene	camphechlor	
1	Trichlorfon	Dipterex Dylox	
1	Trichlorophenol	Collunosol Dowicide 2 or 2S Omal Phenachlor	
1	Triethylamine		
1	Trimethylamine	TMA	
	Uranium compounds		
1	Uranium peroxide		
1	Uranyl acetate		
1	Uranyl nitrate		
1	Uranyl sulfate		
	Vanadium compounds		
1	Vanadium pentoxide	vanadic anhydride vanadic acid anhydride	
1	Vanadyl sulfate	vanadic sulfate vanadium sulfate	
1	Vinyl acetate	acetic acid ethylene ether	
1	Xylene	dimethylbenzene xylol	meta-; ortho-; para-xylene
1	Xylenol	dimethylphenol hydroxydimethyl benzene	
1,2	Zectran	mexacarbate	

	COMMON NAME	SYNONYMS	ISOMERS
	Zinc compounds		
1	Zinc acetate		
1	Zinc ammonium chloride		
1	Zinc borate		
1	Zinc bromide		
1	Zinc carbonate		
1	Zinc chloride	butter of zinc	
1	Zinc fluoride		
1	Zinc formate		
1	Zinc hydrosulfite		
1	Zinc nitrate		
1	Zinc phenolsulfonate	zinc sulfocarbolate	
1,2	Zinc phosphide		
1	Zinc potassium chromate	zinc yellow citron yellow buttercup yellow zinc chrome	
1	Zinc silicofluoride	zinc fluosilicate	
1	Zinc sulfate	white vitriol zinc vitriol white copperas	
1	Zinc sulfate, monohydrate		
	Zirconium compounds		
1	Zirconium acetate		
1	Zirconium potassium fluoride		
1	Zirconium nitrate		
1	Zirconium oxychloride	zirconyl chloride zirconium chloride, basic	
1	Zirconium sulfate	disulfatozirconic acid	
1	Zirconium tetrachloride		

II. DETERMINATION OF REMOVABILITY OF HAZARDOUS SUBSTANCES

"Remove" or "removal" refers to removal of the oil or hazardous substances from the water and shorelines or the taking of such other actions as may be necessary to minimize or mitigate damage to the public health or welfare, including, but not limited to, fish, shellfish, wildlife, and public and private property, shorelines, and beaches. ......

The determination that the designated substances that cannot actually be removed by chemical, physical, or biological means does not relieve the discharger from damage mitigation liabilities under Sections 311(f) and 311(g) of the Act.

III. DETERMINATION OF HAZARDOUS QUANTITIES

The smallest container used in commerce for a typical category A material, for example an inorganic cyanide, is a one-pound (0.454 kilogram) bottle. Consequently, this amount has been chosen as the "harmful quantity" of all category A materials. Other categories are thereafter assigned quantities on a proportional basis as shown in Table II. Basically, if the upper aquatic toxicity limit of a category is ten times higher than the upper limit of the proceeding, more toxic category, then the harmful quantity is set as ten times larger, and so forth.

TABLE II
EPA CATEGORIES
FOR HARMFUL QUANTITY DETERMINATION

Category	Representative Range	Harmful Quantity lb.(kg.)
A	LC50* $<$ 1 ppm	1.0 (0.454)
B	1 ppm $\leq$ LC50 10 ppm	10 (4.54)
C	10 ppm $\leq$ LC50 100 ppm	100 (45.4)
D	100 ppm $\leq$ LC50 500 ppm	500 (227)

* LC50 means that concentration of material which is lethal to one-half of the test population of aquatic animals upon continuous exposure for 96 hours or less.

The representative range means that substances in Category A have LC50 values of less than 1 ppm, Category B substances have LC50 values of 1 ppm or greater up to 10 ppm, Category C substances have LC50 values of 10 ppm or greater up to 100 ppm, and Category D substances have LC50 values of 100 ppm up to and including 500 ppm.

IV. PENALTY RATES

The only common unit of measure is a weight unit, the pound. The penalties using these common units of measure shall be based on the toxicity, degradability, and dispersal characteristics of the substance (Section 311(b)(2)(B)(iv)) in a manner similar to the determination of those quantities of hazardous substances which are harmful to the public health or welfare at certain times, locations, circumstances and conditions (Section 311(b)(4)). Thus the weight corresponding to the smallest commom commercial container size, one pound (0.454 kilogram), previously adopted as the "harmful quantity" for materials in the most toxic EPA harmful quantity category, has also been adopted as the "unit of measurement" for materials in that category and assigned a base penalty rate of $1,000 per unit. Other categories are assigned larger units of measurement which are multiples of the basic one pound unit and are found as a direct proportion between the upper aquatic toxicity limit of the less toxic category and the upper aquatic toxicity limit of Category A substances. The aquatic toxicity ranges for various hazard categories and the units of measurement derived from the appropriate ratios are found in Table II under Harmful Quantities.

The proposed system recognizes that not all substances within a category exert their damaging effects equally. The law requires that the penalties range between $100 and $1,000 per unit of measurement. For each category in the proposed system the upper penalty limit is modified by physical/chemical adjustment factors which reflect the substance's ability of disperse.

The adjustment factor (0.1 to 1.0) arises from a second profiling operation based on the solubility, density, volatility, and associated propensity for dispersal in water of each hazardous substance. Each substance has been placed in one of eight categories combining these physical/chemical/dispersal properties in various ways. The relative harm these categories pose to the environment was then ranked. The terms involved and final relative ranking of physical/chemical/dispersal categories, in increasing order of relative damage potential, are shown in Table 2.

TABLE 2
PHYSICAL/CHEMICAL/DISPERSAL (P/C/D)
ADJUSTMENT FACTORS

Material Classification	P/C/D Category	Rank	P/C/D Factor
Insoluble Volatile Floater	IVF	1	0.10
Insoluble Nonvolatile Floater	INF	2	0.23
Insoluble Sinker	IS	3	0.36
Soluble Mixer	SM	4	0.49
Precipitator	P	5	0.62
Soluble Sinker	SS	6	0.75
Soluble Floater	SF	7	0.88
Miscible	M	8	1.0

LEGEND:

IVF (insoluble volatile floater) - materials lighter than water with a vapor pressure greater than 10 mm Hg and a solubility of less than 1,000 ppm (weight per weight basis) or materials with vapor pressure greater than 100 mm Hg and solubility less than 10,000 ppm.

INF (insoluble nonvolatile floater) - materials lighter than water with a vapor pressure less than 10 mm Hg and solubility less than 1,000 ppm (weight per weight basis).

IS (insoluble sinker) - materials heavier than water and of solubility less than 1,000 ppm (weight per weight basis).

LEGEND: (Cont'd)

SM (soluble mixer) - solid substances which have a solubility greater than 1000 grams of solute per 1000 grams of water.

P (precipitator) - salts which dissociate or hydrolyze in water with subsequent precipitation of a toxic ion.

SS (soluble sinker) - materials heavier than water and a solubility greater than 1,000 ppm (weight per weight basis).

SF (soluble floater) - materials lighter than water and of a solubility greater than 1,000 ppm (weight per weight basis).

M (miscible) - liquid substances which can freely mix with water in any proportion.

In summary, the adjusted rates of penalty, in dollars per unit of measurement, arising from all possible combinations of toxic category and P/C/D factor are seen in Table 3 below.

TABLE 3
RATES OF PENALTY
IN \$/UNIT OF MEASUREMENT*

	P/C/D Classes							
Category	IVF	INF	IS	SM	P	SS	SF	M
A	100	230	360	490	620	750	880	1000
B	100	230	360	490	620	750	880	1000
C	100	230	360	490	620	750	880	1000
D	100	230	360	490	620	750	880	1000

* Unit of measurements for categories are A = 1 lb, B = 10 lb, C = 100 lb, D = 500 lb.

For convenience, Table 4 shows the adjusted rates of penalty, in dollars per pound, for all combinations of toxic category and P/C/D factor.

TABLE 4
RATES OF PENALTY
IN $/LB

Category	P/C/D Classes							
	IVF	INF	IS	SM	P	SS	SF	M
A	100	230	360	490	620	750	880	1000
B	10	23	36	49	62	75	88	100
C	1.0	2.3	3.6	4.9	6.2	7.5	8.8	10
D	0.20	0.46	0.72	0.98	1.2	1.5	1.8	2.0

SHIP UNDERWATER MAINTENANCE, EVALUATION, & REPAIR

(SUMER)

MASTER PLAN

APPENDIX C

FOULING DIAGNOSTICS AND INSPECTION METHODS

PREPARED FOR

NAVAL SEA SYSTEMS COMMAND

PREPARED BY:

Tracor Sciences & Systems

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APPENDIX C

FOULING DIAGNOSTICS AND INSPECTION METHODS

C.1.0 INTRODUCTION

The purpose of developing fouling diagnostics and inspection methods is to determine the optimum time and conditions for the cleaning of ships' underwater hulls. The constant assessment of ships' hulls and consequent periodic wet docking not only maximizes time between drydocking, but has considerable impact on energy conservation owing to greatly reduced fuel usage.

The applicability of several fouling/corrosion diagnostic methods for monitoring fouled hull conditions is discussed in this section. Recommendations are made concerning those methods presently available as well as actions for development of improved diagnostic methods for the future.

The specific objective of this study is to develop cost-effective methods that will be capable of alleviating the necessity of drydocking ships for 'bottom cleaning jobs' for as long as 5 to 7 years. During this 5 to 7 year time frame, the degree of fouling is not to exceed a level at which the ship's speed or fuel consumption will be adversely or substantially affected.

Although several methods are used as course indicators of hull degradation, and others are in the RDT&E stage, there are no well developed or routinely established fouling diagnostics currently used other than subjective inspection of the underwater hull. In exploring diver inspection procedures and related support equipment, it became readily apparent that the need existed to expand the study effort to include the underwater inspection process in its entirety. This need derives from the program objective of developing 5 to 7 year drydock cycles for ships. In order for ships to remain waterborne for such extended periods of time,

C.1.0 INTRODUCTION (Cont'd)

it is necessary to be assured of the integrity or seaworthiness of the hull at all times. Therefore, the type of inspection performed on the ship's underwater hull must be comparable to that which occurs when the ship is drydocked. Thus, the discussion on inspections is of considerable length and includes processes and equipments needed for hull integrity or seaworthiness purposes as well as for fouling diagnostic purposes.

C.1.1 Problem Description

Dramatic increases in ship fuel costs combined with the need to maximize the operating range of Navy ships make it imperative to develop diagnostic methods for evaluating the effect of fouling on ship power and speed. It has been proven conclusively that fouling of the ship's underwater body, including propeller and other appendages, has a significant effect on ship's power requirements and speed. However, a precise means of diagnosing or measuring this effect is not within the normal capability of most ships. Correlation factors relating to the severity, type, location, distribution, and time-rate of fouling growth are needed in order to arrive at economically and operationally sound decisions as to when, how, and where to remove the fouling. Consequently, it is essential to be able to quantify all aspects of fouling. It is necessary to define the trade-offs among such factors as cost of cleaning, paint life, and fuel savings. Therefore, an accurate evaluation and assessment of all related factors must be made available to the decision maker.

C.1.1.1 Background. The one universal fouling diagnostic method currently used, from which only a gross evaluation of the effect of fouling on ship's power can be derived, is diver inspection of the ship's underwater body. Such underwater inspection techniques are highly subjective and are carried out primarily by visual means reinforced by some still photography and television. In addition to being subjective in

C.1.0 INTRODUCTION (Cont'd)

nature, such methods are handicapped, among other things, by a lack of precision in 'mapping' locations of the underwater body, water conditions (visibility, temperature, current), poor knowledge of divers and decision makers on the identity of fouling mechanisms and their growth rates, and low inspection rates.

Systems of quantification and acceptability criteria are essential if underwater hull inspections are to be used successfully. These systems will have to be developed, as none now exist, and confidence in these systems among ship managers will have to be instilled. Credibility of diver inspections is currently considered to be low. Repeatable and demonstrably objective inspection results are required to improve credibility. This in turn requires measuring instruments which are not currently available in service approved form, although several types of instrumentation are in use in the offshore industry and other related Navy and commercial applications.

In order to effect and maintain a 5 to 7 year drydocking cycle for all or even most ships of the Navy, the decision maker must have total confidence in the information presented to him on all the factors relating thereto. Actual data obtained from controlled tests recently conducted by Navy DTNSRDC Code 2705 indicate that torsionmeters provide a degree of accuracy and repeatability of ship power deterioration resulting from fouling. This will give the decision maker, i.e., commanding officer, operational commander, or maintenance officer quantitative high-level confidence information so that he can make economically and operationally sound decisions in a timely manner.

The torsionmeter, or any other hull resistance measuring device or system, only gives the end result of the fouling effect of the underwater body. In order to specify the trade-off points relating to the cost of cleaning versus fuel savings, it is necessary to know the increased resistance and power losses associated with various degrees of

C.1.0 INTRODUCTION (Cont'd)

fouling severity, their types, location, distribution, and growth rates. These elements and associated factors can only be correlated by accurate and repeated inspections of ship's underwater body, propeller, and other appendages. This, coupled with the need to be assured of the physical integrity of the hull and its protection systems (anticorrosion and antifouling) at all times, results in a requirement to be able to conduct underwater inspections to essentially the same degree of thoroughness and accuracy as is now done when a ship is drydocked. More specifically, inspection methods/equipments must be developed which will be as complete, efficient, and reliable as current inspections made in dry dock. Such inspection 'system' must support the hull cleaning project; it must be capable of quantifying fouling severity, type, location, distribution, volume, and roughness, and be able to permit a quantifiable evaluation of the installed anticorrosion and antifouling systems.

A means of identifying and quantifying hull roughness is also essential so that correlation to ship's power/speed deterioration can be predicted. In addition to increased resistance, hull roughness has been shown to increase wake, which results in decreased propeller efficiency. It has also been shown that bottom roughness is more important in this regard than a similar degree of roughness on the sides of the ship.[1*] Such factors of a variable nature lend further credence to the need for accurate and detailed underwater inspection processes.

In order to be cost-effective, the following inspection rates are considered to represent the approximate order of magnitude required, which is considered to be within the current technical state-of-the-art.

- Hull plating, antifouling coating condition, and fouling severity inspected at the rate of 50 to 75 sq. ft. per minute.

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*NOTE: References are listed in Section C.3.10.1 (page C-93).

C.1.0 INTRODUCTION (Cont'd)

- Propellers, struts, tail shafts and other appendages, cathodic protection systems, and sea chest section/ discharges inspected in 2 to 3 days time with between 10 and 30 man-days depending on ship type.

In summary, the objective of a fouling diagnostic and inspection system is to provide Navy ship commanding officers and other decision makers with reliable fundamental data from which cost-effective hull cleaning and hull integrity trade-off decisions can be made during the 5 to 7 year interval between drydockings. In order to meet this objective it is necessary, expressed briefly, to be able to quantify (1) all aspects of fouling, (2) condition of hull coatings, (3) physical integrity of the hull and, (4) power increases associated with fouling or other hull/propeller deterioration. It then becomes necessary to correlate power increase with specific causative fouling factors such as fouling severity, location, distribution, and type. This correlation can come about only by measuring power increase and by a knowledge of the above quantified fouling factors obtained by accurate and repeated inspections of ship's underwater body, propeller, and other appendages.

C.1.1.2 Constraints. There are no known governmental (federal, state, or local) rules or regulations that would constrain the development of any fouling diagnostic concept being contemplated at this time. The Navy Diving Manual must be complied with if Navy divers are to be involved in any manner. The basic constraint established therein is that a four-man team is the minimum team size permitted for shallow water diving.

C.1.1.3 On-going Navy RDT&E Hull Cleaning Efforts. The Navy's Shipboard Energy Conservation R&D Program being pursued by David W. Taylor Naval Ship Research and Development Center (DTNSRDC) in the areas of hull cleaning and formulation of antifouling coatings is closely related to the development of fouling diagnostic and inspection methods discussed

C.1.0 INTRODUCTION (Cont'd)

herein. The hull cleaning portion of the DTNSRDC Code 2705 Energy Conservation Program, which commenced in FY 75, is a 4-year program terminating with FY 78. The elements of this program relating to fouling diagnostics and inspection methods are basically those involving the determination of 'when' and 'how' to clean the underwater hull and appendages of ships and are summarized as follows:

- Evaluation of commercially available hull cleaning methods including assistance to Fleet Commanders in support of hull cleaning efforts
- Development of cleaning methods for Navy ships where gaps exist
- Laboratory evaluation of paint wear with cleaning
- Conduct, by sea trials, economic trade-off analysis between cost of cleaning and fuel costs associated with fouling (hull cleaning frequency determination)
- Determination by sea trials of long term impact of repetitious cleaning
- Development of Fleet instruction on 'when' and 'how' to clean

C.2.0 FINDINGS AND RECOMMENDATIONS

C.2.1 Findings

Formal fouling diagnostic methods and procedures have not been developed for either naval or commercial use. The existence of criteria for fouling diagnosis results largely from the efforts of companies that are involved in hull cleaning. These companies have shown the ship operators that costs can be saved by cleaning the ship waterborne. Ship classification societies are also cooperating with this cost saving effort by conducting inspections with vessels waterborne. The development of underwater inspection tools and equipment has been accelerated by the offshore oil field industry. Specific findings relating to the state-of-the-art, gaps in technology, needed RDT&E effort, and other considerations are listed in more detail in the sections that follow.

C.2.1.1 State-of-the-Art Findings. State-of-the-art findings relating first to fouling diagnostics and then to underwater inspection methods are presented in this section.

C.2.1.1.1 Fouling Diagnostic Findings.

a. Formal fouling diagnostic methods and procedures have not been developed for naval use. The major tool used today for fouling diagnostics is diver inspection. This inspection only gives a subjective view of the fouling condition as the diver has no available standards or criteria with which to compare observed conditions. Many Navy ships' propellers and sonar domes are now being routinely cleaned prior to getting underway for extended operations and/or after extended periods in port.

b. Research leading to the development of a fouling diagnostic system is presently being conducted by DTNSRDC

C.2.1 Findings (Cont'd)

Code 2705 as part of the Energy Conservation Program. This program is utilizing torsionmeters and Sperry Doppler speed logs as well as monitors for propulsion plant parameters to develop a fouling diagnostic method. The current emphasis is on verifying the correlation between shaft horsepower as measured by a torsionmeter and first stage H.P. turbine shell pressure. To date, results have been very encouraging; however, several additional data points will be required over a period of time to obtain an adequate confidence level. If such verification is obtained, a built-in diagnostic tool then exists on all steam-propelled ships—the first stage H.P. turbine shell pressure. However, this turbine shell pressure must be correlated with shaft RPM and ship's speed through the water. The latter requires either speed logs with higher degree of accuracy and repeatability than currently exists in the Fleet, or access to measured ranges which are few in number.

In the event that test results fail to verify high correlation over time between SHP and first stage H.P. turbine shell pressure, the utilization of a torsionmeter and/or other instrumentation will have to be considered as the basic diagnostic tools.

c. The state-of-the-art of torsionmeters is well advanced with thousands of units in use worldwide, many of which are on ships, including approximately 28 currently aboard U.S. Navy ships, most of which were installed for purposes other than for fouling diagnostics. The unit cost of torsionmeters for Navy shipboard application ranges between \$11,000 and \$40,000 with installation costs

C.2.1 Findings (Cont'd)

running between \$8,000 and \$15,000 per unit. Therefore, the use of torsionmeters solely as a diagnostic method will involve a considerable expense.

d. An accurate ship speed measuring device/method is required to complement any power measuring device (torsionmeter, first stage H.P. turbine shell pressure, etc.) in forming a fouling diagnostic system. Essentially, all speed logs on Navy ships are the electromagnetic (EM) type which theoretically can be very accurate. However, many ships experience accuracy errors ranging up to 5 percent or more.

e. Very few measured ranges readily accessible to Fleet units exist which could be traversed to determine accurate ship's speed through the water. Also, very few sites for such visual ranges exist, especially for ships operating out of Navy ports in the southeastern section of the U.S. in that a minimum water depth of 150 feet is required for destroyer type ships. A greater depth is needed for larger ships. This minimum water depth requirement would place the ship about 25 miles off the coastline and thus out of visual range of the range markers.

f. Speed logs exist which may prove to have the required degree of accuracy for fouling diagnostic purposes. The Sperry Doppler SRD-301 currently being evaluated by DTNSRDC Code 2705 Energy Conservation Program appears to provide such accuracy. It is possible that a properly calibrated EM log may have a useful speed range within which the degree of accuracy is high enough for fouling diagnostic purposes. This has yet to be explored. The Westinghouse ACULOG has the potential to be very accurate; however, the elements external to the ship's hull consist

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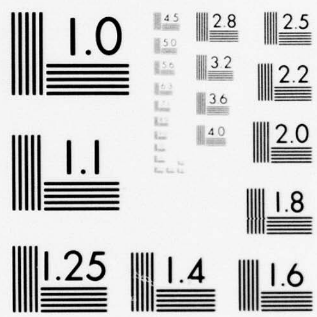

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

C.2.1 Findings (Cont'd)

of three sword-like devices which in turn are subject to deterioration by fouling and damage.

g. Several other techniques have potential as fouling diagnostic methods. However, they exist either in concept form or as just rough diagnostic indicators at the present time and, therefore, require developmental effort in varying degrees. These concepts and techniques may be summarized as follows:

- Electrical Measurements of Hull Coating. Measurement of the electrical resistance of hull coating through impressed current cathodic protection system instrumentation provides a rough indication of the condition of the hull coating at the present time. NAVSEC 6101C is studying this technique. Further development of the technique, refined instrumentation, and correlation factors are required to determine the effectiveness of this technique.

- Temperature/Flow Differential Monitoring. Monitoring flow rates and temperature differentials in the seawater side of heat exchangers and other seawater piping systems offers an exciting prospect of diagnosing fouling of sea chests and associated piping systems. There is no current ongoing effort in this area; however, the state-of-the-art of sensors and algorithms necessary for the development of a fouling diagnostic system are well established.

- Propulsion Parameter Correlation. In addition to first stage H.P. turbine shell pressure as part of a fouling diagnostic system, other propulsion plant parameters

C.2.1 Findings (Cont'd)

may also prove valuable. Condensate flow, condenser pressure, and temperature could be monitored and a program designed to correlate these parameters with ship fouling could be instituted. Several software programs of this nature have been designed in the aerospace industry with positive results. No other related effort is known.

- Measured Distance at Constant RPM. This concept is in limited use in merchant ships for fouling diagnostics and the distance used is either the port to port distance or the distance between navigational fixes. A principal limitation of this method is the limited availability of measured mile ranges convenient to Navy operating areas. It is possible, however, to use navigational satellites for obtaining real-time fixes over long distances by those one hundred plus Navy ships so equipped. For this information to be accurate, it is necessary to compute out all effects of wind, sea state, ship pitch, etc.; this is currently very difficult to do for other than very low wind and sea state conditions. No RDT&E is needed other than the development of a computational scheme and collection of baseline data if this method is adopted for diagnostic purposes.

- Noise Measurement. Noise measurements are routinely made by submarines and occasionally surface ships to ensure that they are not radiating excessive noise. Without being thought of as a diagnostic tool, noise levels are being used in the submarine community as an indication of excessive fouling and other noise

C.2.1 Findings (Cont'd)

producing sources. Although the equipment and technology are presently available to obtain noise signatures of ships, the technological gap which exists today and prevents general use of noise as a fouling diagnostic indicator is the correlation between the level and frequency of the noise and a quantified level of fouling. This concept also has the disadvantage that it militates against the individual ship determining when to clean.

- Time Indexing. Most fouling diagnostic systems in use today, especially in the maritime field, are based on time. The average time-based criteria utilized by several commercial companies are to clean the ship's bottom after nine months out of dry dock and then every three to four months thereafter. A more methodical scheme of indexing could yield more accurate results. A fouling point system could be implemented now using arbitrary standards such as 1 point for a day in a known fouling port, 1/8 point when underway at more than 15 knots, etc. An accumulation of, say, 100 points could then be cause for cleaning. The details of the point system could be worked out on a feedback system. However, the biological phenomena which govern fouling and the interaction with various protective systems are not fully understood. Also, the complexity of fouling dependence on location and time makes it difficult to define in a sufficiently precise manner. An active research program would have to be pursued to obtain a data base for each port.

C.2.1 Findings (Cont'd)

h. Hull resistance due to plate roughness increases with service life and with the size, depth, shape, and frequency of roughness as factors in resistance. Plate roughness due to corrosion, coatings, and surface preparation can contribute to resistance increases as great as 30 percent even in the absence of visible fouling. Therefore, methods of quantitatively evaluating hull coating roughness and detecting corrosion beneath the coatings are needed in addition to the power loss as measured by torsionmeters or other forms of power meters.

i. Decisions to clean the hull or perform other forms of maintenance thereon will frequently be based on more complex factors than cost-benefit trade-offs. This is particularly true of sonar domes whose cleaning is determined by operational considerations.

j. Cost-benefit trade-off decisions can be quite varied depending upon the time integration of different effects. For example, a growth of barnacles 3/8" in diameter may have a small effect on hull resistance and therefore signify small immediate savings if removed. However, as barnacles increase above that size, they tend to become difficult to remove, in addition to having a deleterious effect on the paint and eventually the hull plating itself. Therefore, a cost-benefit analysis over longer time periods, say five to seven years, may indicate that cleaning when barnacles are 3/8" in diameter is cost-effective independent of the condition or extent of other foulants.

C.2.1 Findings (Cont'd)

k. Regardless of the measurement techniques involved in determining the increased hull resistance caused by fouling or hull roughness, it is necessary to actually inspect the underwater hull so as to confirm and evaluate the fouling as to location, extent, type, etc., to arrive at the proper maintenance action to be taken.

C.2.1.1.2 Underwater Inspection Findings. The findings addressed in this section relate to the state-of-the-art associated with the two functional types of underwater hull inspections: (1) inspections as a fouling diagnostic method and (2) inspections relating to the physical integrity or seaworthiness of the hull of Navy ships.

a. Underwater hull inspections are currently conducted by divers who have received little or no training in conducting either fouling inspections or hull integrity inspections.

b. The Underwater Work Techniques Manual gives little guidance for conducting underwater inspections.

c. No standards exist to aid divers in diagnosing fouling type and quantification thereof.

d. Standardized procedures for conducting an underwater inspection are not in use although the Underwater Work Techniques Manual contains a suggested report format. However, this form is not in general use and, consequently, the quality of underwater inspection varies from command to command.

e. No standard diver inspection tools exist; however, most divers have assembled an assortment of tools that are relatively effective in aiding them.

C.2.1 Findings (Cont'd)

f. The Navy has virtually no capability for conducting NDT inspections with the ship waterborne. What capability that does exist results from judicious use of flexible plastic covers for land-based equipment which can utilize a long cable between the sensor and the readout devices.

g. Several commercial companies are involved in the field of underwater inspection who use the full range of NDT equipment.

h. The most widespread hull/swimmer location device employed by Navy divers is the use of keel hauling lines.

i. Acoustic pinger location devices are emerging from the developmental phase and after suitable evaluation should become available to Navy divers. NCSL is conducting effort on such a system.

j. U.S. Navy divers are trained from almost any rating group and frequently have less than adequate organizational support. In the Royal Navy (British), diver is a rate and underwater inspection is a functional part of the rate.

k. Navy divers do not have standard work boats from which to work. Various adaptations of existing available boats have been made but few are equipped for effective operation.

l. COMNAVSEA INST 9597.1 contains a listing of approved diver support equipment. However, few fleet diving units have all the essential equipments listed therein because funding for initial outfitting of approved equipments is generally from the users' O&MN funds which are always in short supply. Thus, as new and better tools are developed,

C.2.1 Findings (Cont'd)

they frequently do not become available to the diver because funds are not specifically designated for such purposes.

m. There are no measurement instruments for quantification of the following parameters available to Navy divers for underwater inspection purposes:

- Crack detection
- Leak detection
- Fouling level
- Corrosion deterioriation
- Liquid level, oil/water
- Surface profile or roughness
- Coating evaluation

n. In the commercial ship industry, divers are used as observers in many cases where a problem is suspected. However, for required ship inspections, trained surveyors are used. Some inspections are being conducted with the inspector/surveyor topside observing a closed circuit TV monitor from a diver-held camera. The SCAN system, used by Underwater Maintenance Co., Ltd., in Las Palmas, Canary Islands, positions the TV camera by remote control.

Some companies are considering training their qualified inspector/surveyors as divers.

o. Clear-field underwater viewing devices, generally of an ad hoc nature, are in limited use in commercial diving operations; however, none have been officially designated for Navy use.

C.2.1 Findings (Cont'd)

p. NCSL has recently been assigned responsibility for development, test, and evaluation of diver inspection tools. Funding commensurate with this responsibility has not been provided.

q. Historically, efforts relating to ship underwater hull maintenance have lacked coherency in both management and funding support. The bulk of the required RDT&E effort relating to underwater hull inspections is deemed to be in the Engineering Development (6.4) and Operational Systems Development (6.6) categories. However, most of the past funding for inspection-related efforts has been largely of the Exploratory Development (6.2) and Advanced Development (6.3) categories.

C.2.2 Recommendations

This section contains recommendations consisting of two parts—recommendations relating to fouling diagnostic methods followed by recommendations concerning underwater hull inspections.

C.2.2.1 Fouling Diagnostic Recommendations. It is recommended that:

- In the absence of any formal fouling diagnostic program, Navy ships in tropical waters be cleaned at 4 to 6 month intervals and ships in temperate waters be cleaned at 9 to 12 month intervals, based on underwater inspections every 3 months. This is the procedure currently being recommended by DTNSRDC Code 2705.

- A fouling diagnostic data bank be established. All data on fouling trials and feedback from underwater diagnostic inspections to be included in this data bank.

C.2.2 <u>Recommendations</u> (Cont'd)

- Torsionmeters not be procured and installed on ships solely for use as a fouling diagnostic tool until results of DTNSRDC Code 2705 Energy Conservation Program show conclusively that no other less costly method will be available in the near future.
- Ships equipped with torsionmeters be required to traverse existing measured ranges (e.g., Guantanamo Bay, Cuba; Roosevelt Roads, P.R.; Barbers Point, Oahu, etc.) in accordance with established speed/power trial procedures periodically when in the vicinity of such ranges recording SHP and other appropriate data and send to DTNSRDC for evaluation and analysis.
- After ships complete drydocking with a new underwater hull coating, their performance be cataloged to form a baseline for diagnostics. The performance parameters selected to be tailored to individual ships. For example, H.P. turbine pressure, torsionmeters, speed logs, etc., may be most appropriate for some ships while others may employ fixed ranges and precision navigation (OMEGA, SATNAV) in place of speed logs.
- An R&D effort be directed toward development of high accuracy speed logs commencing with modifying existing types to improve accuracy or repeatability to the degree required for use as part of a fouling diagnostic system.
- The present DTNSRDC Code 2705 Energy Conservation Program's data baseline accumulation work be expanded as follows:
  - To investigate the correlation of other propulsion plant parameters, including condensate flow, steam quality, etc., with shaft horsepower and ship speed.

C.2.2 Recommendations (Cont'd)

This correlation may either improve or complement the level of information derived from the correlation of H.P. turbine shell pressure with shaft horsepower. Also, this effort, coordinated with the Code 2705 machinery efficiency program, may lead to a cost-effective fouling diagnostic method especially when incorporated into the design of new ships or new engineering plants.

- Conduct sea trials of currently installed EM speed logs to determine existence of a speed range/window within which, when log properly calibrated, the indicated ship's speed is sufficiently accurate or repeatable/predictable to serve as part of a fouling diagnostic system.
- Evaluate cost-benefit trade-offs for the proposed five- to seven-year drydocking integration times so that optimization results include important second order effects such as hull plating as well as coating deterioration.

• In order to be able to evaluate the effect of frictional resistance and assess its economic impact, the following be developed:

  - Standard measurement techniques for describing surface profiles to permit quantification of roughness.
  - Correlation of in-service speed loss data with surface roughness and time out of dry dock.
  - Correlation of standard profiles and hydrodynamic smoothness

C.2.2 Recommendations (Cont'd)

- Diagnostics indicated by measurement techniques to be confirmed and pinpointed by diver inspection. This inspection is necessary for a proper decision to be made with regard to the specific of the maintenance action.

Additional funding required for DTNSRDC to implement the foregoing recommendations having significant funding impact is estimated as follows:

	FY-$K				
	77	78	79	80	81
• Establish and maintain data bank	200	200	150	150	150
• Expand DTNSRDC diagnostic effort, including propulsion plant parameters and speed log development/evaluation	350	350	350	350	350

C.2.2.2 Underwater Inspection Recommendations. Recommendations relating to the several elements of an underwater hull inspection system are provided in this section under the identified elements.

C.2.2.2.1 Diver Inspection Systems.

a. Life support equipment. It is recommended that:

- Approved life support equipment be provided to each hull husbandry diving activity to ensure that each activity has a complete inventory of approved equipment for shallow water diving.
- A new diver face mask which does not restrict visibility be developed for hull husbandry divers.

C.2.2 Recommendations (Cont'd)

- The UNI-SUIT be approved for use in a variable volume configuration and be procured for hull husbandry use.
- Currently approved diver air compressors be procured for each hull husbandry diving activity.
- A surface umbilical be approved for hull husbandry use and be provided to each hull husbandry diving unit.

b. Video equipment. It is recommended that:

- Commercially available underwater TV systems, including color, be evaluated to determine if they have greater capability than UDATS for underwater hull inspections. This evaluation should include the feasibility of utilizing components of the system such as lights and cameras with existing UDATS monitoring and controlling equipment.
- The Navy consider standardization of component cable interfaces of TV systems so that improved components can be added as they are developed.
- Commercially available photographic equipment be evaluated for inspection purposes.

c. Measurement Instruments. It is recommended that measurement instruments be developed and evaluated for the following:

- Tank liquid level, including oil/water interface
- Fouling level, quantification of
- Surface profile/roughness for both hull and propeller
- Leak detection
- Corrosion rate (local and general)

C.2.2 Recommendations (Cont'd)

- Coating effectiveness
- Crack detection (may be by NDT device)
- Hull plate thickness (may be by NDT device)

d. Non-Destructive Test (NDT) Equipment. It is recommended that commercially available underwater NDT equipment of the following categories be evaluated for Navy underwater use:

- Wet magnetic particle
- Ultrasonic
- Eddy current
- Gamma radiography

e. In evaluating the foregoing types of equipments, the following approach is recommended:

- Organize an evaluation team consisting of Navy laboratory, shipyard NDT, Navy Photo Center, and shipyard/tender diving and engineering personnel.
- Select the most promising equipment and evaluate in terms of training requirements, operability, reliability, maintainability, support, and human engineering factors.
- Collect and process data required to obtain service approval for equipment procurement.
- Issue approved equipment to Fleet units and provide appropriate training.

f. Working Platforms/Boats. It is recommended that LCM-3 work boats configured as in NAVSEA Drawing No. 145-4777404

C.2.2 Recommendations (Cont'd)

Code Ident. 80064 be designated as the standard diver work boat for afloat activities and be procured for each afloat hull husbandry diving activity. For more efficient operations, ashore activities may require a larger boat. In either case, the diver work boats should be outfitted with the following:

- Air compressors and air bottles
- Dry area for TV monitors and communication equipment
- Welding equipment
- Repair equipment
- Electric, hydraulic, and pneumatic power supplies for cleaning and other equipments
- Warm area
- Suit storage
- Tool lockers

g. Swimmer Locator/Navigation System. It is recommended that:

- A high priority hull location R&D effort be initiated immediately.
- Development of the NCSL swimmer area navigation or comparable system be expedited.
- A lightweight net type grid and/or a two-line triangulation location device be developed.

h. Software. It is recommended that:

- A training program be developed immediately for Navy divers on hull fouling inspection/diagnostic procedures.

C.2.2 Recommendations (Cont'd)

This could be an expansion of DTNSRDC Code 2841 current efforts in support of COMSUBLANT. Coverage to include foulant identification and their growth characteristics and effects on ship's power as a function of location, size, and density as well as the relative importance of fouling properties.

- A training program be instituted immediately on qualifying hull inspectors/surveyors at shipyards and other maintenance activities as shallow water divers.
- Standards for evaluating underwater inspection results be provided to the underwater inspector. For hull integrity inspections, these standards should be as close as possible to existing drydock inspection standards. For fouling diagnostics, divers should be provided with color photographs of hulls in various conditions of fouling with an approved verbal description of the fouling level. DTNSRDC is currently developing inspection procedures relating to hull cleaning which are planned to be presented in an interim instruction to the Fleet in FY 77.
- Underwater hull inspection procedures and reports be standardized.
- The Underwater Work Techniques Manual be reissued to all hull husbandry diving activities. The manual should also be updated to include inspection standards.
- The Sonar Dome Handbooks, Volumes I through IV, be updated (as has been done with Volume V) to include underwater hull inspection requirements and procedures, with particular applicability to AN/SQS-26 sonar domes with rubber windows.

C.2.2 Recommendations (Cont'd)

C.2.2.2.2. Fixed, Remote, and Mobile Inspections. It is recommended that:

- One port on each coast with clear water and little current be designated as a hull integrity inspection facility.
- Feasibility studies be undertaken to determine the cost-effectiveness of fixed and mobile inspection facilities.
- Hull Inspection Platform (HIP), a mobile inspection vehicle designed by NUC, be redesigned for ship inspections and be evaluated for use as an inspection vehicle. Underwater lighting, TV, and a manipulator arm, fitted, for example, with devices for sea chest inspection and cleaning, should be included in the design.
- SCAN inspection system be evaluated for Navy use.

C.2.2.3 Funding. It is recommended that:

- NCSL be adequately funded to expedite the development, test and evaluation of tools, equipments, techniques, and procedures recommended above.
- Funding of inspection-related tools and equipment be controlled at NAVSEA and that initial allowances and newly approved equipments be centrally funded instead of funding by user activities O&MN funds.

C.2.2.3.1 Underwater Inspection System Program Funding Recommendations. Recommendations having significant funding impact beyond the scope of the ongoing DTNSRDC Code 2705 Energy Conservation Program are summarized and listed below in order of priority within each funding category. Funding levels recommended are only class "F" budget estimates.

C.2.2 Recommendations (Cont'd)

			FISCAL YEAR $K				
	RDT&E	ACTION	77	78	79	80	81
1.	Develop Inspection Program	NCSL/ DTNSRDC	200	300	200	200	50
2.	Develop Measurement Instruments	NCSL	100	100	75	75	75
3.	Develop Locator Systems	NCSL	100	100			
4.	Develop Clear-field Viewing Devices	NCSL	25	25	25	25	25
5.	Redesign HIP System	NUC	150	150			
6.	Evaluate SCAN	NCSL	50	50			
7.	Evaluate Underwater NDT Equipment	NCSL	100	100	50	50	50
8.	Improve Underwater TV	NCSL	100	100	100	100	75
9.	Improve Life Support Equipment	NAVSEA	50	50	50	50	50
	O&MN						
1.	Conduct Diver-Inspecting Training	NAVSEA	150	150	150	50	50
2.	Determine Training Inspector as Diver Feasibility	NAVSEA	50				
3.	Revise and Republish Underwater Work Techniques Manual	NAVSEA	50	25	20	20	20
4.	Establish Clear Water Pilot Fleet Facilities Inspection/Evaluation	NAVSEA/ FLT CDR	200	50	50	50	50
5.	Update Sonar Dome Handbooks	NAVSEC	50	50	50	--	--

C.2.2 Recommendations (Cont'd)

	OPN/SCN	ACTION	FISCAL YEAR $K 77	78	79	80	81
1.	Establish and procure full allowance tools, equipments, and systems for diver-inspection units	NAVSEA	500	500	600	600	500
2.	Procure Standardized Diver Work Boats (20 at $250K)	NAVSEA	1000	1000	1000	1000	1000

C.2.2.4 Effectiveness Evaluation Plans. Effectiveness evaluation plans for both fouling diagnostics and underwater hull integrity inspection systems will be based largely on empirical data and feedback.

It is recommended that a comparative analysis be used to evaluate the effectiveness of the fouling diagnostic system. After, say, every second or third hull cleaning based on a diagnostic trade-off analysis, the ship will immediately conduct another at-sea trial, using the same diagnostic method to measure the decrease in hull resistance resulting from the cleaning. The resulting iterative feedback process will lead to refinement and further improvement in the diagnostics. This is the approach being used by DTNSRDC Code 2705 to develop frequency determination and other criteria for cleanings.

The most objective criterion by which to evaluate the effectiveness of the underwater hull integrity inspection process is to conduct and document such an inspection immediately prior to a regular scheduled drydocking of a ship. The comparative analysis of the pre- and post-drydocking inspections provides an excellent evaluation of the effectiveness of the underwater hull inspection. This process also allows more than one team of inspectors to be evaluated by just one drydocking.

In making cost-benefit trade-off decisions pertaining to hull fouling-cleaning, it must be kept in mind that for Navy ships cost-effectiveness criteria also include mission performance. That is, pure dollar

C.2.2 Recommendations (Cont'd)

cost trade-off points are not always in the best interest of the Navy. For example, it may be necessary to clean sonar domes more frequently and at greater cost than the associated fuel cost savings would indicate. However, it may be cost-effective to clean propellers each time a ship gets underway after a relatively short period in port because of the great impact roughness has on propeller efficiency.

These two general concepts should provide the basis for developing a more detailed effectiveness evaluation plan after the program is implemented.

C.2.2.5 Development Progress Tracking Plan. The development progress tracking plan is addressed in the context of the overall program, rather than on the basis of individual diagnostic methods or concepts. This approach is desirable because of the interrelationships among the various diagnostic methods considered in Section C.3. Until specific diagnostic methods are decided upon, only broad program policy guidance is warranted. Accordingly, this section discusses policy considerations relating to development progress tracking plans.

There are three essential elements to consider in establishing a development progress tracking plan. These elements comprise a monitoring center, a communications network, and a reporting system.

The function of the monitoring center is to track and review the programs being followed, with respect to both the administrative and the technical activities of the program. An efficient monitoring center with data bank is required because of the broad scope and the variety of participants in the program. The work efforts and other activities to be tracked are dispersed literally worldwide and include overlap between commercial and naval efforts.

The communications network is needed to provide input data to the monitoring center, as well as output to the performing activities.

C.2.2 Recommendations (Cont'd)

This network should serve both the administrative and the information requirements of the monitoring center, performing the following functions:

- Coordination of information flow and data handling
- Progress monitoring
  - Field support activities
  - Shipyards and facility support
  - Laboratories (Navy and commercial)
  - Shipboard pilot projects
  - Worldwide commercial R&D efforts
  - RDT&E milestones
- Systems and equipment status
  - Acquisition
  - Acceptance
  - Inventory
  - Distribution
- Cost data
  - For program reviews
  - For cost-effectiveness evaluation

The reporting system function is to keep management informed of overall program status and progress and to disseminate information to performing activities. Periodic reviews of the various projects and tasks will be required; results of these reviews may impact other projects. Reports also provide a vehicle for initiating the establishment of diagnostic procedures and criteria, for follow-up on developments or problems, and for program modification.

C.2.2 Recommendations (Cont'd)

The monitoring center, communication network, and reporting system should be established soonest, in order to begin the integration of ongoing efforts into the overall program. These essential elements will assist the program manager to effectively and efficiently coordinate the program. Once established, they will also enable him to make plans for expansion, to consider the development of timely R&D projects, and to take action on procurement of long lead-time items needed for program development and support.

C.2.2.6 Policy and Organizational Recommendations. Effective implementation of the foregoing recommendations requires the establishment of an appropriately structured organization having well-defined lines of control. The key to such an organization is a strong program manager and charter in NAVSEA with appropriate OPNAV sponsorship. The recommended structure required to direct an integrated hull husbandry program includes the following:

- Program Sponsor in CNO
- Program Manager in NAVSEA
- Advisory Committee
- Task Groups
- Industry Support

C.3.0 DISCUSSION

This section contains results on an in-depth survey of existing methods, state-of-the-art technology, and new approaches relating to fouling diagnostics and underwater hull inspections. The survey includes ongoing Navy programs, and programs of other U.S. Government agencies as well as foreign and domestic commerical efforts involving underwater hull husbandry and related efforts of offshore industries. The new approaches are primarily based on the condition of parameters fundamental to plant operation.

C.3.1 Introduction

Although coarse indicators of hull degradation are used, there are no well developed or routinely established fouling diagnostic programs currently in use by the U.S. Navy. However, ongoing tests being conducted by DTNSRDC Code 2705, Energy Conservation Program, indicate that power measuring instrumentation has the potential to become a basic unit of an accurate fouling diagnostic system. In addition, a survey of the state-of-the-art indicates that it may be possible to correlate several parameters of the ship's power plant in order to obtain a constant monitor on ship's hull condition.

The current technology used in many fouling diagnostic concepts is based on the fact that hull resistance increases as surface roughness increases. The problem then becomes one of measuring the change in hull resistance as the ship becomes fouled. There are several ways in which this can be accomplished. One of the oldest concepts (and a difficult one) for measuring hull resistance is to tow the ship at a fixed speed in calm water and to measure the tension in the towing line. Increases in towing line tension as the hull becomes fouled can then be correlated with the amount of fouling, the amount of power required, or the loss in speed encountered, provided an accurate measure of all the parameters is obtained.

C.3.1 Introduction (Cont'd)

Interestingly, if the speed and power on a real-time basis are available, other more reliable correlations and approaches are available. Several old as well as novel approaches such as using external propulsive power, coasting techniques, electric drives, etc. suffer since they tend not to be easily repeatable, stable, and are expensive and difficult tools to use for constant real-time monitoring. This leads to the question of exactly which are the preferred methods of diagnostics that are cost-effective and can be used for constant monitoring.

One way to assess the condition of the hull is to monitor the time and fuel rate usage as a ship traverses a fixed and known distance under reproducible conditions. Then, time and fuel rate become indicators of the hull condition in that as the hull deteriorates, the time to traverse a fixed distance at constant fuel rate increases. This means that the fuel usage goes up in order to maintain a given speed as time measured from dry dock elapses. The difficulties with this method are, of course, (1) the lack of fixed ranges located near ship operating areas and (2) the difficulty of obtaining reproducible environmental conditions. Another difficulty relates to the problem of ensuring repeatable propulsion plant efficiencies for successive trials.

The use of torsionmeters in conjunction with ship speed is another method that gives an indication of the increased shaft horsepower necessary to maintain ship speed as a function of time. The difficulty here is associated with the fact that any fouling of the propeller cannot be separated from the effects of hull fouling. The torsionmeter, when used to measure shaft horsepower, only gives the end result of the fouling effect of the underwater body and/or propeller. It does not differentiate between the power increases associated with increased hull resistance due to fouling and decreased propeller efficiency caused by fouling. In order to differentiate between these two deleterious factors in a rigorous manner, it is necessary to measure the thrust applied at the main propulsion

C.3.1 Introduction (Cont'd)

thrust bearings. Thrust measuring devices which operate on hydraulic or strain gauge principles are used by Navy on a limited scale during some trials of new ships. However, there are many problems associated with the use of thrust measuring devices aboard ship that militate against their use either as a test or an operationally effective device. These include costs, both initial and installation; maintenance of calibration; accuracy; and sensitivity to ship trim and dynamics.[2] Consequently, it is considered more practical to use well-trained diver inspectors as the basic means by which the effects of propeller fouling are differentiated from the total power increase as measured by the torsionmeter. This is based on several factors, (1) the assumption that divers will be required for underwater cleaning, repair, and hull integrity inspections, (2) the propeller is easily and readily located by divers and can be inspected for fouling or roughness by feel by well-trained divers in low visibility conditions, and (3) the assumption that means of correlating various degrees of propeller fouling or roughness to specific power increases for operational use aboard ship will be developed in the near time frame. A significant problem associated with the use of torsionmeters is the necessity of obtaining true ship speed or an accurate indicated speed through the water.

Other fouling diagnostic methods that are dependent upon the correlation of parameters such as turbine pressure, condenser temperatures, shaft horsepower and RPM etc. all require some indication of ship speed. Therefore, fundamental to the development of several diagnostic methods is an accurate ship speed determination.

There are several methods and available instrumentation used for ship speed determination. Briefly, they can be summarized as follows:

- Marine log type SAL-24 (Junger) works on the principle of pressure transmission and requires calibration via measured mile runs.

C.3.1 Introduction (Cont'd)

- EM log (Chesapeake) is based on the electromagnetic induction principle and requires calibration via measured mile runs.
- ACULOG (Westinghouse) works on the principle of different times of transit of acoustic signals with and against flow. This also requires calibration via measured mile runs.
- SRD-301 doppler speed log (Sperry) is based on doppler techniques requiring no shipboard calibration if installed with sensor in region of undisturbed water flow.

It is important that a very careful survey of these instruments be made and compared in order to obtain the most desirable speed information for diagnostic purposes.

In addition to instrumentation and correlations, it is clear that inspection also plays an important role in diagnostics. For this purpose, it will be necessary to train personnel to develop an objective and repeatable inspection system that can yield quantifiable information. Clearly, therefore, a quantifiable, accurate, and repeatable underwater inspection system must be developed, especially during the initial stages of the development of a fouling diagnostic system, to ensure that the physical integrity of the hull is maintained. Therefore, the discussion of underwater hull inspections as a fouling diagnostic method is combined with the development of hull integrity inspection requirements and systems in the final subsection of this discussion.

The remaining sections present the results of an in-depth survey of the state-of-the-art technology as well as new approaches related to fouling diagnostics and underwater hull inspections. An overview of the diagnostics is illustrated in Table C-1.

TABLE C-1. FOULING AND CORROSION DIAGNOSTIC AN

	TORSIONMETER	ELECTRICAL MEASUREMENTS IMP. CURRENT	ELECTRICAL MEASUREMENTS RESIST., CAP.	TEMP/FLOW DIFF MONITORING	PROPULSION PARAMETER CORRELATION	MEASURED DISTANC AT CONSTANT RPM
STATE OF THE ART	• Current torsionmeters work on one of four basic principles • Three available that meet Navy specs	• Automatic systems available • No Navy specs	• Conceptual	• Physical and mathematical concepts well understood • Diagnostic aid not developed	• Parameter correlation techniques well known • Use as diagnostic aid not developed • Technique well established in aerospace industry	• Technique devel for performance monitoring • Not used as diag tic aid
CONSTRAINTS	• Use in conjunction with shaft rpm • If ship speed (v) and Ω not correlated, then V needed	• Diagnostic information very coarse • High correlation with coating deterioration	• Measurement of changes in coatings R, C, difficult	• No hardware • Techniques for diagnostic not developed	• No hardware • Techniques for diagnostic not developed	• Lack of baselin • Algorithm for diagnostic analy not developed • Measured course not readily available
GAPS IN TECHNOLOGY	• Higher accuracy in speed log • Correlation data	• Need refined measurement of T • Methods for quantification	N/A	• Development of algorithms and necessary software	• Development of algorithms and necessary software	• None
RDT&E NEEDED	• Shipboard T&E • Long-term reliability and stability • Integration with shipboard instrumentation (Expand NSRDC Code 2705 related work)	• Accurate methods for monitoring conditioning of hull coating • Integration	• Quantify coating • Lab testing • Correlation studies	• Experiment design • Full-scale experimentation • Data interpretation and analysis	• Continue present work (NSRDC - Code 2705) • Expand data base to include other parameters • Data interpretation and analysis	• Correlation betw time change at Ω with fouling
STATUS	• Most fundamental instrumentation • Forms baseline information for other potentially more cost-effective methods • Over 25 units in fleet	• Currently used in some cases • No baseline information available	N/A	• Concept	• HP turbine pressure used as plant performance indicator for long time • HP turbine pressure, Ω, V being currently correlated. (NSRDC-Code 2705) • No other parameter correlation under study	• Several experim
PERSONNEL CONSIDERATIONS	• Minimal impact on shipboard personnel • Simple basic indoctrination in OPS and care	• Special indoctrination required in data logging and interpretation	N/A	N/A	N/A	N/A
IMPLEMENTATION	• Can be used on those ships that are equipped with torsionmeters	• Currently available during ROH • Installed on 1/3 of fleet	N/A	• Subject to results of above RDT&E	• Subject to results of above RDT&E	• Available subje to constraints

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1. FOULING AND CORROSION DIAGNOSTIC AND INSPECTION METHODS

TEMP/FLOW DIFF MONITORING	PROPULSION PARAMETER CORRELATION	MEASURED DISTANCE AT CONSTANT RPM	TIME INDEXING	ACOUSTICS	DIVER INSPECTIONS	FIXED, MOBILE, AND REMOTE INSPECTION
Physical and mathematical concepts well understood Diagnostic aid not developed	• Parameter correlation techniques well known • Use as diagnostic aid not developed • Technique well established in aerospace industry	• Technique developed for performance monitoring • Not used as diagnostic aid	• Not used as diagnostic aid • Could be employed in the near future • Conceptual	• Self-noise increases with fouling • Correlation does not exist • Not used for diagnostics	• Presently in use • No standards	• Currently not used for fouling diagnostics
No hardware Techniques for diagnostic not developed	• No hardware • Techniques for diagnostic not developed	• Lack of baseline • Algorithm for diagnostic analysis not developed • Measured course not readily available	• Accuracy is unknown • Subjective but based on accumulated data	• Interference from other sources	• Visibility • Diver location • Environmental • Work platform	• Following hull contour and propeller • Visibility • Electrical interference
Development of algorithms and necessary software	• Development of algorithms and necessary software	• None	• Biological phenomena not quantifiable	• Instrumentation	• No standards • No diagnostic tools • Fouling not quantified	• Mobile and remote unit hardware for hull integrity inspection • No hardware for fixed facility
Experiment design Full-scale experimentation Data interpretation and analysis	• Continue present work (NSRDC - Code 2705) • Expand data base to include other parameters • Data interpretation and analysis	• Correlation between time change at fixed Ω with fouling	• Development of data base for each port • Design of suitable algorithm	• Identification of noise due to fouling • Correlation studies	• Quantify fouling • Develop standards and tools	• Feasibility studies for all • Further development for HIP
Concept	• HP turbine pressure used as plant performance indicator for long time • HP turbine pressure, Ω, V being currently correlated. (NSRDC-Code 2705) • No other parameter correlation under study	• Several experiments	• Conceptual	• Conceptual	• Most basic • Currently used • Highly subjective	• Mobile (HIP) unit in development
N/A	N/A	N/A	N/A	N/A	• Lack of training • Motivation	• Utilize trained hull inspectors • Minimal additional training
Subject to results of above RDT&E	• Subject to results of above RDT&E	• Available subject to constraints	• Requires further analyses	• Requires studies of basic work	• In use for observational purposes	• Subject to further development

2

C.3.2 Torsionmeters

Since an increase in propeller RPM, to maintain a fixed ship speed, is required as a function of days out of dry dock, the correlation of this information suggests a method for fouling diagnosis. For the method to be implemented, it is necessary to obtain the following information as a function of time:

- Shaft horsepower developed
- Ship speed

C.3.2.1 State-of-the-Art. The shaft horsepower developed by a ship can be conveniently obtained by the use of an appropriate torsionmeter. A torsionmeter is placed on the ship's main propulsion shafting to measure the instantaneous torque being applied to the propeller. Knowing the modulus of elasticity of the shaft, its RPM, and torque, the shaft horsepower is readily determined. A survey of several torsionmeters appears in Annex C-I. Details of the Mark I MTI device are well documented by NAVSHIPS and are not reproduced in Annex C-I. Also, the instrumentation by Lebow is not included since this class of information is covered by others and has a lower torque/power range than required for most Navy ships.

The current population of ships equipped with torsionmeters is very small. The DD 963 class is equipped with ACUREX strain gauge torsionmeters on each main propulsion shaft. Approximately 20 MTI (Mechanical Technology Incorporated) "torductor" type torsionmeters are in the fleet on the CGN-36, 37, and 38, the CVN-68, SSN 688 Class and on some CV's. A SHIPALT has been issued for the installation of MTI torsionmeters on all CV's for the purpose of preventing over-torquing the propulsion system because of the hull fouling. The installation of torsionmeters on the other ship/submarine classes listed above is for other reasons; however, this does not preclude their utilization as a fouling diagnostic tool.

C.3.2 Torsionmeters (Cont'd)

The use of a torsionmeter as a fouling diagnostic tool requires the monitoring of shaft RPM and ship speed. The ship speed is currently generally obtained with an electromagnetic (EM) log for speed measurement. The EM log rodmeter protrudes from the hull, measuring the velocity of the water passing by. Experience has shown that the typical EM log installation, especially aboard Navy combatant ships, does not have the accuracy or repeatability required for trial purposes. The rodmeter and sensing electrodes are subject to fouling and to any changes in the water flow characteristic in the vicinity of the sensor. Hence, rodmeter measurements are subject to water flow changes due to fouling and hull cleaning. Therefore, for fouling diagnosis or whenever an accurate measurement of ship speed is required, it is recommended that a measurement of the time to traverse a known range be made, or an alternate approach such as Sperry's SRD-301 Doppler Speed Log be further refined.

Once shaft horsepower and ship speed are obtained, an algorithm needs to be designed for correcting the effect of other parameters such as ship's displacement, trim, wind direction and speed, currents, and sea state as well as the ship's dynamics.

C.3.2.2 Technology Gaps. The principal gaps in technology are:

- Higher accuracy needed in speed logs
- Correlation data

Higher speed log accuracy is required since the error in the correlation between torsionmeter reading and speed is almost entirely due to error in accurate speed determination. Correlation data on a long-term basis is needed to assess the stability of the instrumentation.

C.3.2.3 Needed RDT&E. For the fouling diagnosis to be effective, a program to assure repeatability, stability, and reliability must be undertaken as a part of this effort. The required RDT&E can be summarized as follows:

C.3.2 Torsionmeters (Cont'd)

- Continued shipboard T&E
- Long term reliability and stability
- Integration with shipboard instrumentation

Currently, the torsionmeter and its associated software are installed as experimental devices and independent of other instrumentation. Once the experimental phase is over, it will be necessary to integrate this instrumentation with other shipboard instrumentation.

C.3.2.4 Environmental Considerations. No environmental problems are anticipated.

C.3.2.5 Personnel Considerations. Owing to the relatively simple nature of this instrumentation, there should be minimal impact on shipboard personnel. The only requirement will be basic indoctrination on the operation and care of the instrumentation as well as interpretation of results obtained during monitoring.

C.3.2.6 Equipment Support. There is no equipment other than a low voltage power supply for the software electronics.

C.3.3 Electrical Measurements of Hull Coating

An impressed current cathodic protection system contains the elements for diagnosing the integrity of hull coatings on an overall or average basis. The deviation of the reference cell against set voltage is essentially an indication of the degree of corrosion and/or deterioration of the hull coating.

Essentially, all new ships are being built with an impressed current cathodic protection system. SHIPALT's have been issued to install impressed current cathodic protection systems in nearly all classes of ships that are not currently so equipped. Utilization of the systems reference cell, along with appropriate algorithm and circuitry, provides

C.3.3 Electrical Measurements of Hull Coating (Cont'd)

a conceptual method of measuring the effectiveness of the antifouling hull coating by its electrical resistance. Indications from this system could serve as a monitoring or warning system that the antifouling coating was deteriorating and that the corrective maintenance thereto was required. These systems as presently configured provide diagnostic information only of a very gross and subjective nature. Also, hull coating deterioration can occur much slower than fouling build-up; therefore, this concept may be of very limited use.

Modifications as indicated above could improve the diagnostic capability significantly.

C.3.3.1 State-of-the-Art. An indication that the hull coating system has seriously deteriorated is when the voltage of the reference cell cannot be maintained at the protective potential. In other words, so much deterioration has occurred to the hull coating that the capacity of the power supply has been exceeded, such that it cannot deliver enough current to protect the hull.

Work is also progressing on a more accurate method for monitoring the condition of hull coating by Naval Ship Engineering Center (NAVSEC) Code 6101. This method is to measure the 'time constant' on the potential. The time constant is the period needed to make a specified increase in potential for a specified power output. Low time constants (such as in seconds) are associated with effectively intact coatings, while large time constants (such as in minutes or hours) are associated with deteriorated coatings.

The state-of-the-art is currently limited to the above scheme and does not include any available technologies that can measure corrosion rates on a local basis. Although such measurements are state-of-the-art for industrial applications, they have not been developed for ship use. For example, Petrolite Instruments Corp., Stafford, Texas 77477,

C.3.3 Electrical Measurements of Hull Coating (Cont'd)

has a line of corrosion meters for food, chemical, and other industries but they have not developed hardware for shipboard use. These instruments generally utilize a test electrode that does not take into account the ratio of anode area to cathode area existing on a ship that is inducing galvanic current nor take into account the effects of hull coating deterioration. The effect of hull coating deterioration is to cause a continuous change in the anode to cathode area ratios. Therefore, such instruments presently designed are not effective in measuring corrosion rate of a ship's underwater hull. Further study is needed to determine the application of these type instruments as viable hull corrosion meters. Petrolite is currently investigating techniques for inhibiting seawater corrosion of water tanks.

Cathodic protection system parameters, as well as other electrical parameters, are not now used as a fouling diagnostic tool by the U.S. Navy and no application of this method has been found in the commercial area. More accurate methods of measurements for the cathodic protection systems as well as new techniques for measurement of electrical parameters is necessary before this can be used as an effective diagnostic tool.

C.3.3.2 Technology Gaps. The use of cathodic protection system and other electrical parameters as a fouling diagnostic tool is presently just a concept. There is almost no technology established on which to base the utilization of this system for fouling diagnostics. What is known is that the impressed current system usually requires more power as the time out of dock increases.

The measurement of such electrical properties of hull coatings as resistance, capacitance, and 'time constant' of potential can give an indication of their anticorrosive and perhaps antifouling effectiveness. However, there are currently no known correlation factors which would

C.3.3 Electrical Measurements of Hull Coating (Cont'd)

relate the value of these properties to any degree of fouling corrosion. Therefore, a system for obtaining the necessary electrical measurements and correlating these to quantified coating conditions would be required before this concept could be used as a meaningful diagnostic.

This general area of correlating the condition of hull coatings with electrical measurements appears to be a promising diagnostic tool requiring a long-term R&D effort.

C.3.3.3 Needed RDT&E. Laboratory tests are needed to correlate electrical measurements with condition of coating. Panels of hull materials, e.g., ship steels or marine aluminum alloys, should be covered with the coatings currently used (or proposed) for hull protection. These coated panels should be exposed to seawater and periodic measurements over long periods of time taken of electrical resistance, capacitance, and 'time constant' of potential. The panels should be examined from time to time, so that the condition of the coating can be noted and correlated to the value of electrical measurement. It is necessary that the coating condition be quantified. Essentially, the electrical measurement versus time curves are calibration curves on the effectiveness of the coating to protect the underlying substrate. These calibration curves could be used in monitoring the hull coatings aboard U.S. Navy ships.

The system for making the electrical measurements, i.e., resistance, capacitance, 'time constant' of potential, aboard ship is needed. For those ships having an impressed current cathodic protection system, the installed electrical equipment should be used as much as possible. For example, the reference cells (electrodes) could be connected to a device that would measure the time constant directly and even plot this time constant on a strip chart, so that the change in time constant over extended periods of time can be monitored and compared to the corresponding calibration curve on coating effectiveness. This equipment development involves design, shipboard installation, and test

C.3.3 Electrical Measurements of Hull Coating (Cont'd)

at sea. The measurements taken at sea should be compared to the calibration curves taken in the laboratory. The condition of hull coating examined when the ship is drydocked should be related to the values of electrical measurements taken prior to drydocking. Correlation is then needed between shipboard electrical measurements and laboratory measurements for various levels of coating effectiveness.

The electrical measurement versus time data taken in the laboratory and aboard ship must be carefully analyzed and interpreted. The analysis is needed to develop operational doctrine for drydocking a ship to repair/replace the hull protective coating. The electrical measurement versus time plots must have the proper interpretation defined for the captain of the ship to alert him that the hull coating must be repaired. In other words, criteria based on the electrical data must be established to alert the captain. The alert can be two stages:

- A yellow alert that the hull coating has deteriorated to the point where plans must be made to repair the coating.
- A red alert that the hull coating is seriously impaired and that coating repair is needed in the near future.

Finally, detailed planning is needed to implement a research and development (R&D) program for a shipboard electrical system for diagnosing the integrity of hull coatings.

C.3.3.4 Environmental Considerations. No adverse impact anticipated.

C.3.3.5 Personnel Considerations. If the diagnostic concept of using impressed current cathodic protection system parameters is adopted, there should not be any need for additional personnel to operate the equipment, maintain the equipment, or record data.

Training of cognizant shipboard engineering personnel to make proper and timely measurements would result in only a minor burden to ship's crew.

C.3.3 Electrical Measurements of Hull Coating (Cont'd)

C.3.3.6 Equipment Support. Calibration and test equipment for the instrumentation developed would be required. Software in the form of operating procedures and records would be essential to successful implementation of such a fouling/corrosion diagnostic method. The actual needs can only be established after some RDT&E is completed.

C.3.4 Temperature/Flow Differential Monitoring

It has been well established that fouling on the sea chest strainer plate cuts down drastically the intake area and also the amount of seawater that can flow through the condensers and other heat exchangers and seawater piping systems. Therefore, measuring the velocity of entering seawater, a small distance downstream from the sea chest, offers a means of developing a seawater piping system fouling diagnostic.

C.3.4.1 State-of-the-Art. The fundamental scientific principles underlying the proposed concept have been well established although not used in the present context. The state-of-the-art as far as the principle is concerned is best understood by reviewing the steady state behavior.

Under steady state conditions, the product of the velocity and the effective cross-sectional area at location 1 is equal to that at location 2 shown in Figure C-1. Right after drydocking, this is a maximum. Clearly, the velocity at point 2 is directly correlated with the ship's velocity. If this correlation is established, then the constant monitoring of the velocity at point 1 allows the determination of the effective area at cross-section 2. This is only true provided the cross-section at point 1 is itself not noticeably diminished by fouling. For this diagnostic approach to be implemented, the following information is required:

- Monitoring of the velocity of the intake, upstream from the sea chest

C.3.4 Temperature/Flow Differential Monitoring (Cont'd)

- Monitoring of the ship's velocity
- Effective cross-sectional area at locations 1 and 2

It may be desirable to correlate this information with a visual inspection of the sea chest.

A second scheme depends upon the quantity of heat transferred from the engine/pump room into the flowing seawater. Ordinarily, the amount of heat transferred is dependent on the heat transfer coefficient of convection inside and outside the pipe, thermal conductivity of the pipe, and the temperature difference between engine/pump room and seawater flowing through the pipe. As the fouling builds up inside the pipe, the coefficient of heat transfer due to convection decreases. It is possible to predict this inside heat transfer coefficient by making measurements of certain selected temperatures. Specifically, we need to monitor the following at location 1:

- Temperature of seawater at the center of pipe
- Temperature at surface of pipe
- Temperature of the engine/pump room outside the pipe

This scheme works as a diagnostic aid as long as there is a temperature gradient between the seawater and engine/pump room. It is perhaps worth noting that such a scheme has also been recommended for monitoring fouling effects on the heat transfer coefficients in the heat exchangers of solar seawater power plants (SSPP).

C.3.4.2 Technology Gaps. The instrumentation needed for measuring temperature and flow conditions is currently available. The only gap then exists in the development of suitable computational algorithms and the necessary software.

C.3.4.3 Needed RDT&E. Since the principles are well understood and instrumentation is available, it is recommended that RDT&E be carried

C.3.4 Temperature/Flow Differential Monitoring (Cont'd)

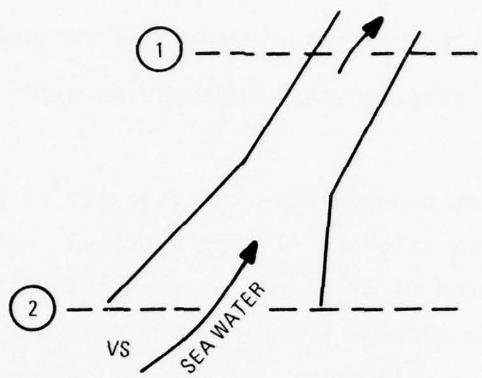

Figure C-1. Sea Chest Intake

out to support an experimental program. The RDT&E required for this is:

- Design of suitable equipment
- Full scale experimentation
- Data interpretation and analysis

C.3.4.4 Environmental Considerations. No impact in this area is anticipated.

C.3.4.5 Personnel Considerations. Although no additional shipboard personnel will be required, the extent and nature of training needed to log and analyze data can be determined after RDT&E is completed.

C.3.4.6 Equipment Support. Other than some power (less than 100 watts) for software electronics, no additional support is anticipated.

C.3.5 Propulsion Parameter Correlation

There are several parameters available on board a ship that could be correlated with each other yielding relationships that could

C.3.5 Propulsion Parameter Correlation (Cont'd)

be used as diagnostic aids. During runs, parameters such as turbine pressure, condensate flow, condenser pressure and temperatures, ship speed, etc., could be monitored and a program designed to correlate these parameters could be instituted. Any positive correlation could then be used for diagnostic purposes. Several software programs have been designed in the aerospace industry with positive results.

C.3.5.1 State-of-the-Art. Recently, the Navy began an effort in the Energy R&D office at DTNSRDC to use the USS HAROLD E. HOLT (FF-1074) for making correlation studies in order to come up with an assessment technique for indicating the extent of hull/propeller fouling. Specifically, during trial runs, the first stage H.P. turbine pressure was correlated with the shaft horsepower. It was found that a near linear relationship existed with a correlation coefficient approaching unity. Additional work is progressing in that shaft horsepower is being correlated with the ship speed in order to establish the effects of fouling. If the correlation between the first stage H.P. turbine shell pressure and shaft horsepower is repeatable over a period of time, an important diagnostic aid would be available, viz, the correlation between ship speed and the first stage H.P. turbine shell pressure. This information gives an indication of the hull condition and allows for a scheme to predict the time at which it is cost-effective to drydock.

C.3.5.2 Technology Gaps. Instruments for automatic reading of temperatures, pressures, flow rates, and shaft horsepower are currently available and with sufficient accuracy to be useful for this application, although not normally installed aboard ships. Therefore, no technology gap exists in this regard. However, necessary computational algorithms and supporting software would have to be developed to relate this to fouling.

C.3.5.3 Needed RDT&E. Since parameter correlations are currently being studied by DTNSRDC Code 2705, it is recommended that this work

C.3.5 Propulsion Parameter Correlation (Cont'd)

be enlarged to include other parameters. Specifically, it is suggested that:

- Present work at DTNSRDC Code 2705 continue
- Data base be expanded to include additional parameters previously mentioned (see Section C.2.2.1) such as condensate flow, steam quality, as well as temperatures and pressures at key points in the propulsion system
- A program be established to analyze resulting correlations

C.3.5.4 Environmental Considerations. No adverse environmental effects are anticipated.

C.3.5.5 Personnel Considerations. Although no additional shipboard personnel will be required, the extent and nature of training needed to log and analyze data can be determined after RDT&E is completed.

C.3.5.6 Equipment Support. Other than some power (less than 100 watts) for software electronics, no additional support is anticipated.

C.3.6 Measured Distance At Constant RPM

The time required to travel a fixed distance is a measure of the ship's average speed. If this fixed distance is run with the ship maintaining a constant RPM, the time to traverse the distance will increase as fouling increases as long as ambient conditions are the same.

C.3.6.1 State-of-the-Art. If a fixed and measured distance is available so that a ship could traverse it back and forth, then the time it takes to traverse this distance becomes an indication of its speed provided the shaft RPM is constant. Actually, the time is inversely proportional to the velocity and as the velocity drops at constant RPM one gets an indication of degradation by fouling if a comparison is made with baseline data obtained right after drydocking work. The principal limitation of this scheme is the limited availability of measured mile ranges convenient to

C.3.6 Measured Distance At Constant RPM (Cont'd)

Navy operating areas. It is possible, however, to use satellites for obtaining real-time fixes by those one hundred plus ships so equipped and compute distance traveled. For this information to be accurate, it is necessary to compute-out all effects due to sea state, wind, etc., which is currently very difficult to do in all but very low wind and sea states.

This concept is in limited use in the merchant fleet for fouling diagnostics, but the distance used is either the port to port distance or the distance between navigation fixes. This can be done because much merchant shipping runs at constant RPM's for long periods of time over the same routes. The Exxon-Butterworth system recommends cleaning the hull when the ship speed decreases 1/2 knot.

C.3.6.2 Technology Gaps. If measurement courses are not readily available and satellite fixes are used, then the necessary software needs to be developed. The necessary technology exists, however.

C.3.6.3 Needed RDT&E. No RDT&E is needed other than collection of baseline data once this method is adopted for diagnostic purposes. If a sufficient number of measurement courses are not available, a program to evaluate the use of satellite fixes should be established.

C.3.6.4 Environmental Considerations. No adverse environmental effects are anticipated.

C.3.6.5 Personnel Considerations. No additional personnel are required. Very minimal training in logging and interpreting data is anticipated.

C.3.6.6 Equipment Support. None required.

C.3.7 Noise Measurement

Through the years, fouling has become recognized as a source of own-ships' noise which degrades the performance of installed sonar systems. The concept of using this noise as a fouling diagnostic tool may be worth pursuing.

C.3.7 Noise Measurement (Cont'd)

As water flows past any surface which is not hydrodynamically smooth, the water is forced into excursions which are necessary to maintain continuity of flow. These excursions generate random noise which usually has a wave length proportional to the size of the object or discontinuity. This noise usually shows up as high frequency sound and is therefore subject to more rapid decay than other sounds.

C.3.7.1 State-of-the-Art. Noise measurements are routinely made by Navy submarines and occasionally surface ships to ensure that they are not radiating excessive noise. Equipment for recording and analyzing this noise is also available and is in use at selected sites. Without being thought of as a diagnostic tool, noise levels are being used in the submarine community as an indicator of excessive fouling and other noise producing sources.

C.3.7.2 Technology Gaps. Although the equipment and technology are presently available to obtain noise signatures of ships and submarines, the technological gap which exists today and prevents general use of noise as a fouling diagnostic indicator is the correlation between the level of noise and the level of fouling. There is also a problem in interpreting the noise data with the exclusion of extraneous noises such as high frequency harmonics and random background water noises.

C.3.7.3 Needed RDT&E. An RDT&E program to use own-ships' noise as a fouling diagnostic indicator would have to pursue two paths. First, DTNSRDC, Carderock, or other activity would have to identify the data processing equipment and criteria which would best show the fouling produced noise and provide correlation of this noise with observed fouling.

The second path would be to correlate information obtained from presently installed own-ships' noise monitors with fouling condition on submarines. This will require a complete visual inspection of the underwater body each time the own-ships' noise monitors exceed the presently established level.

C.3.7 Noise Measurement (Cont'd)

The results of this RDT&E program would be utilized to obtain the best method for obtaining and analyzing this data.

C.3.7.4 Environmental Considerations. The use of own-ships' noise as a fouling diagnostic tool would not have any environmental effect.

C.3.7.5 Personnel Considerations. If own-ships' noise is to be used as a fouling diagnostic tool, the personnel requirements will depend on the method used to obtain and evaluate this information.

If the installed own-ships' noise monitors presently installed on submarines are considered adequate for this function, then no additional personnel would be required. However, additional training would be required for personnel to monitor and maintain this equipment on ships which do not now have the equipment installed.

If additional equipment is required, the personnel considerations will depend on the equipment and the mode of operation. A fixed hydrophone array with one set of monitoring equipment for each major Navy port will require additional personnel, either civilian or military, but will not require the procurement and installation of as many pieces of hardware as would be required for shipboard installation.

C.3.7.6 Equipment Support. Equipment support will be dependent on the results of the R&D program. It could range from procurement of monitoring equipment for each Navy ship to the installation of special monitoring facilities.

C.3.8 Time Indexing

Most fouling diagnostic systems in use today are based on time. This is expected as it allows data to be correlated between many experiments or trials. The most common use of time is a plot of the power required against time out of dock. An analysis of this data leads to the conclusion that most ships collect little fouling during the first few

C.3.8 Time Indexing (Cont'd)

months out of dock and frequently reach the 10 percent extra power level between the ninth and twelfth month. Plots of fouling rate after hull cleaning show that the 10 percent power level is reached much sooner, quite often at about 3 months. Using these results, a time based diagnostic system can be established.

C.3.8.1 State-of-the-Art. Based on experience, one could decide that ships should be cleaned, say, 9 months out of dry dock and then every 3 to 4 months thereafter. However, a more methodical scheme of indexing could yield useful results. We observe that although sea conditions, current, speed, etc., all have an effect on fouling, no concrete correlations are currently available. However, some locations and conditions are more conducive to fouling than others. Based on this available fact, every location could be given a relative rank (say from 1 to 10) where 1 refers to poor conditions for fouling.

The proposed time indexing system would assign fouling points to the ship for each day. The points would be based on where the ship is and what it is doing. When the ship obtained the required number of points, the ship could then be cleaned.

The state-of-the-art in time indexed fouling diagnostics is such that it could be employed today with some assurance of accuracy. As in most diagnostic systems, the need to clean is not based entirely on the diagnostic system but on a visual inspection which is conducted after the diagnostic indicator exceeds its specifications. With time based diagnostic systems this does occur.

The fouling point system could also be implemented today using arbitrary standards such as 1 point for a day in a known fouling port, 1/4 point underway less than 10 knots, and 1/8 point for underway more than 15 knots. An accumulation of, say, 100 points could then be cause for cleaning. The details of the point system could be worked out on a feedback basis; however, a considerable data base is required.

C.3.8 Time Indexing (Cont'd)

C.3.8.2 Technology Gaps. The point system proposed in the previous paragraph and, in fact, all time based systems are examples of statistical analysis of limited data. The biological phenomenon which governs fouling and the interaction with various protective systems is not fully understood.

C.3.8.3 Needed RDT&E. The statistical data base on fouling versus time must be increased. The amount of data presently available is small and most of it is not being utilized as a diagnostic data base. NAVSEC and DTNSRDC, Annapolis, are now receiving this data but only in regard to underwater cleaning procedures. An active program would have to be pursued to obtain a data base for each port. The information should also enable an analysis of the effect of ship's speed on fouling for each basic fouling organism. Samples of water should also be analyzed to determine a correlation between the water and ship fouling which will lead to a simple test to be conducted by each ship for self determination of the fouling potential.

C.3.8.4 Environmental Considerations. Fouling diagnostics based on time will have no effect on the environment.

C.3.8.5 Personnel Considerations. This system of basing the amount of fouling on time should not require any additional personnel or training. If a self fouling potential diagnostic kit is developed, it will require some small amount of training in its use.

C.3.8.6 Equipment Support. No equipment support required.

C.3.9 Underwater Body Hull Inspections

As mentioned previously in Section C.1.1.1, current underwater inspection methods are highly subjective. Quantifiable and repeatable inspection results and associated evaluation criteria are needed not only to permit rational and cost-effective maintenance and repair action decisions, but also to permit the development of a complete fouling

C.3.9 Underwater Body Hull Inspections (Cont'd)

diagnostic system. The achievement of objective inspection and evaluation standards will alleviate the need for drydock inspections more frequent than every 5 to 7 years.

Before exploring current underwater hull inspection methods and equipments, it is desirable to develop the basic requirements to be met by a viable underwater hull inspection system and program if it is to meet the above needs.

Requirements for top-level underwater hull inspections were reviewed in discussions with the Naval Coastal Systems Laboratory (NCSL), Panama City, Florida, and with Fleet personnel. In addition, reports from NCSL, from the Maritime Administration (MARAD), and from related industries were reviewed. The inspection requirements developed from these sources include:

- Acceptable information on which to base repair and maintenance (including hull grooming) action decisions
- Low maintenance and high reliability of hardware
- Low manpower requirements for inspection and hardware maintenance
- Skill levels of inspectors compatible with equipment sophistication, and with accuracy and credibility requirements for making the necessary action decisions
- Operator safety

In meeting these requirements, it is also necessary to determine:

- The set of conditions (fouling, bent propellers, degree of hull corrosion, etc.) which must be found satisfactory prior to determining the hull and hull appurtenances (sonar domes, rudders, sea chests, etc.) to be satisfactory

C.3.9 Underwater Body Hull Inspections (Cont'd)

- For the hull and for each appurtenance or condition:
  - An objective measurement system or reliable go/no-go criteria
  - The functional requirements for measurement or observation tools
- Quantified indications of current inspection capabilities
- The reliability and logistic requirements for available and developed hardware

Development of the following specific software and hardware elements is required.

1. Software
   - A list of all features and conditions to be inspected
   - Sampling criteria for measurements or observations on a statistical basis
   - Data reduction and interpretation systems
   - Quantified conditions and criteria of acceptability for hull appurtenances
   - Baseline for comparative evaluation
2. Hardware
   - Crack detection
   - Leak detection
   - Fouling level measurement
   - Corrosion deterioration measurement
   - Hull thickness gauging

C.3.9 Underwater Body Hull Inspections (Cont'd)

- Coating condition (physical and chemical)
- Liquid level, oil/water indicator
- Detection of looseness and integrity of attached structures
- Sonar dome integrity, smoothness, etc.
- Propeller condition

Some instruments relative to the above requirements exist primarily for use with ships when drydocked, such as propeller pitchometers.

To conduct comprehensive, accurate inspections of the underwater hulls of ships cost-effectively, a complete inspection 'system' must be developed, comprising properly trained personnel and sufficient, adequate, and reliable support equipment. In the case of inspections by divers, the system would include life support equipment, satisfactory working platforms, suitably designed tools, and training.

Many individual equipments designed for diver use are available, but there is no formally designated and completely integrated diver hull inspection system. Therefore, before discussing specific equipments and methods in use or applicable to diver underwater inspections, it is necessary to define the elements of a complete diver inspection system. The major elements and examples of subelements of such a system are:

1. Life-Support Equipment
   - Suits, helmets, air (primary and secondary)
2. Inspection-Related Equipment
   - Video equipment
     - TV, photographic, recorders

C.3.9 Underwater Body Hull Inspections (Cont'd)

- Measurement Instruments
  - Pit depth gauges
- NDT Equipment
  - X-ray, ultrasonics, dye penetrant

3. Working Platform
   - Boat (standard) and equipment
4. Underbody Hull Location System
   - Hogging lines, acoustic pingers, grid markings
5. Software
   - Training, inspection standards, and reports (standard)

C.3.9.1 State-of-the-Art. A state-of-the-art study of underwater inspection methods and equipments was sponsored in fiscal year 1976 by Commander, Naval Sea Systems Command's Ocean Engineering Research and Technology Branch, NAVSEA-0353. The study, completed in June 1976, was conducted by NCSL. The NCSL report, "State-of-the-Art Study—Diver and Remote Vehicle Underwater Inspection," is attached herewith as Annex C-II and will serve as the baseline for further discussions of underwater inspection methods and systems. Data for the report was obtained through contact with cognizant organizations in the United States and foreign countries, including both manufacturers and user activites.

Data is presented for photographic, television, non-destructive testing, and remote inspection systems. The report also makes known the equipment and methods available and lists the sources of supply, prices, and inspection rates where possible. An additional basic purpose was to recommend the developments and evolutions that appear essential for Navy ship and submarines underwater inspection in connection with the overall ship husbandry program.

C.3.9 Underwater Body Hull Inspections (Cont'd)

As mentioned above, the NCSL report will serve as the baseline for further discussion of underwater inspection. The following additional information is provided to supplement the NCSL report.

C.3.9.1.1 Diver Inspection Systems. Many individual equipments have been designed for diver use, but there is no formally designated and totally integrated diver hull inspection system. The two documents that come nearest to addressing this topic are: (1) COMNAVSEA INST 9597.1[3] of 18 March 1976, which lists approved diver equipment and (2) the Underwater Work Techniques Manual (NAVSHIPS 0994-007-8010), Volume II. The latter document lists tools required for about 34 different inspections. However, neither of these documents list all equipments needed to conduct underwater hull inspections.

Hull husbandry divers are usually a small group within a command, and receive little dedicated funding support for their needs. Navy Fleet diving units do not have all the essential equipments listed in NAVSEA INST 9597.1 because funding for Fleet introduction or initial outfitting of approved new equipments is generally from the user commands' O&MN funds, which are always in short supply. Thus, as new and better tools are developed, they frequently do not become available to the diver because funds are not specifically designated for such purposes.

Another major problem area is training. Inasmuch as hull husbandry is a recently awakened art, the state of diver training relating thereto is very low.

As a result, not only the state-of-the-art, but also the expertise of Navy diver inspection capabilities varies from activity to activity.

A state-of-the-art discussion of diver inspection equipments is presented in the section that follows.

C.3.9 Underwater Body Hull Inspections (Cont'd)

C.3.9.1.1.1 Diver Life-Support Equipment. The most closely managed element relating to underwater inspections is diver life-support equipment. The Navy Diving Manual contains extensive guidance and specific regulations pertaining to life-support equipment. Comments on selected state-of-the-art diver equipments follow:

- Masks. The Navy's only approved diver shallow water masks are the "USN" Divers Mask, MK 1 Mods 0, S, and T.[3] Effort is underway on development of a new band mask and of the Mk 12 helmet for deep sea use, which would also be applicable to underwater hull husbandry for inspection and repair efforts. The Mk 1 mask restricts peripheral vision of divers in tight spaces. Little use of SCUBA or Mk V mask is encountered in hull husbandry work.

- Suits. Discussions with a large number of divers from the Atlantic Fleet diving community in June 1976 revealed their dissatisfaction with the current wet-suits for extended underwater operations. They are unanimous in their need for the Poseidon UNI-SUIT for extended time in most water temperatures other than tropical and subtropical. The Poseidon UNI-SUIT is the only currently Navy approved dry suit. Its present configuration is one of constant volume; however, NAVSEA-00C expects approval shortly of a variable volume configuration, which should overcome the discomfort because of improper fit that some divers experience.

- Air Compressors. Approved shallow water diving compressors are listed in NAVSEA INST 9597.1.[3] These equipments are among those that must be procured by the user command from its normal O&MN funds.

C.3.9 Underwater Body Hull Inspections (Cont'd)

- Umbilicals. No approved umbilical exists for shallow water use. The U.S. Navy Diving Manual, page 4-18, requires a surface umbilical as part of minimum lightweight diving equipment.
- Fins. Divers are authorized to use fins of their own preference.

C.3.9.1.1.2 Inspection-Related Equipment.

Underwater TV Systems

Many underwater TV systems are presently available on the commercial market. Tables 3-2 and 3-3 of Annex C-II include manufacturer's data for a number of such equipments. The U.S. Navy is presently using the Underwater Damage Assessment Television System (UDATS) manufactured by Hydro-Products. This system consists of a Model TC-125D1 Camera, Model SC-3-3HW Control Unit, Model LT-8 Light Assembly, Model AV-3650 Video Tape Recorder, and a Model KMB-10 Kirby Morgan Mask.

The UDATS has been used by many Navy activities with varying degrees of success. The Underwater Ship Husbandry Workshop, conducted in January 1975 and sponsored by the U.S. Navy Supervisor of Diving, discussed this system and made some recommendations for improvements.[4] One area of improvement which was not discussed is the need for color television.

Color TV cameras are available for underwater use, but cameras tested by Underwater Maintenance Company, Ltd. of Southampton, England, were judged not to have the required light sensitivity for hull inspection purposes.[5] This company conducts underwater ship inspections in the Canary Islands where the waters are very clear. Color pictures used in these inspections for examination of details are made with a 35 mm still camera.

C.3.9 Underwater Body Hull Inspections (Cont'd)

Cohu, Inc., San Diego, California, markets a Color TV camera (Model 1220) which is claimed by the manufacturer to be suitable for depths to 250 ft. This camera is available with several different intensified image lenses for low light level work. Its application to hull husbandry has not been demonstrated.[6]

MARAD issued a report in July 1974 on the effectiveness of underwater television equipment.[7] In a series of five tests, equipment from four manufacturers was evaluated in Galveston Harbor. An analysis of the tests indicates the following:

- Clear, recognizable pictures can be taken with TV cameras and transmitted through submarine cables to a distant monitor.
- Television is subject to interference generated by electrical and welding equipment in operation near the site of the inspection.
- Water conditions play a very important role in the successfull performance of underwater inspection. In spite of equipment manufacturers' claims, there is a limit to the capacity of camera and light systems to penetrate turbid water. The sites for inspection will have to be selected with care, and will be subject to change.
- Still color photographs (stereo and otherwise) taken underwater in some circumstances are superior to TV pictures.
- Tapes of TV pictures were noted to be superior to those viewed in the monitor at the time of the trial. Audio commentary can be introduced into the tape during or after the test.

C.3.9 Underwater Body Hull Inspections (Cont'd)

- Briefing the diver prior to the inspection speeds the inspection.
- Orientation marks are a necessary aid to the diver. The small field of view sometimes needed makes remote identification difficult.
- Communication is required between the diver and the surface.
- Inspection by diver is time consuming.
- Adjusting lighting to fit water conditions is difficult.

These comments indicate some of the problems of utilizing underwater TV as an inspection tool. Since 1974, several companies have developed improved underwater lighting systems and crude, but effective small area clear-field viewing devices. The Naval Coastal Systems Laboratory has also been developing and evaluating such equipments.

Innerspace, Inc., Dickinson, Texas, a company that has been engaged in underwater hull inspection and cleaning of commercial vessels for several years, recommends the following three underwater TV systems for the reasons indicated:[8]

1. Hydro-Products, San Diego, California. Model "Surveyor". Estimated Cost - $15,140.

   Lightweight; focus 3 inches to infinity with optional remote focus; provides high resolution picture down to light levels as low as 0.02 foot candles at the sensor tube; Surveyor camera/light unit mounts to any type diving hat using a unique "template" interface molded to fit the particular helmet; pistol grip handle also permits hand-held operation. One fault - system is restricted to a tape reel size of 5" in diameter.

C.3.9 Underwater Body Hull Inspections (Cont'd)

2. General Aquadyne, Santa Barbara, California. Model Observer II. Estimated Cost - $16,000.

   This monitor and recorder is also encased, as with the others, in a suitcase type housing. However, the system entails only one case. This unit is restricted to 5" diameter reels, 1/2" wide 30 min. tapes. The coaxial cable for power to the camera and video transmission to the surface gives the system a capability of up to 2000 feet in length from monitor to job site.

3. UDI Group, Houston, Texas. Model UDI "Seafly". Estimated cost - $20,000.

   This system is comparable in specifications to both the General Aquadyne unit and the Hydro-Products unit, except that it is a hand-held unit. A solid-state D.C. to A.C. converter can also be supplied for operation from batteries. The whole system is continued in two aluminum suitcases and can be taken as personal baggage on aircraft.

   The camera and light assembly weighs only 2 pounds in the water and can be made neutrally buoyant if required. UDI has a new underwater cable in which weight is dramatically reduced to one-half pound per 100 feet of length underwater. Reliability of the system is primarily due to the fact that all the power components are constructed underrated to assure the maximum life of the unit.

   UDI is a leading supplier of underwater TV systems to the North Sea oil industry.

   As with the General Aquadyne system and the Hydro-Products system there is an integral two wire diver communication system package. The intercom system can be adapted to any mask or helmet in the commercial diving industry.

C.3.9 Underwater Body Hull Inspections (Cont'd)

In summation, Innerspace, Inc., finds through much experience that in diver working ability, considering visibility and swimming in currents, the General Aquadyne system is the most advantageous. This is because the camera is enclosed in the diver's helmet out of 'harms way' and leaves his hands free.

A contrary point of view was expressed by Supervisor of Diving, Charleston Navy Shipyard.[9] His divers have found the hand-held TV essential in viewing the interior of sea chests and other openings too small to accommodate the diver's head/helmet.

Measurement Instruments

Until recent years, diver inspection tools have been very primitive. The Underwater Work Techniques Manual (NAVSHIPS 0994-007-8010) Vol. 2 lists the tools required for about 34 different inspections in Part 3 of the manual. These tools are:

- Calipers, inside spring
- Calipers, outside spring
- Gauge, screw pitch, set
- Gauge, thickness feeler, set
- Gauge, wire, standard gauge, set
- Gauge, pit depth
- Ruler, folding, 6 feet
- Clay, impression

The proceedings of the Ship Husbandry Workshop in January 1975[4] indicate that inspection is performed on about 47 percent of ship husbandry related dives. Inspections involve all important aspects of underwater hull features more or less equally. Visual inspections are

C.3.9 Underwater Body Hull Inspections (Cont'd)

most common. The civilian ship husbandry diver is using the same tools that the Navy is using, but the commercial market for hull husbandry diving and underwater inspection is still in its infancy. Companies in the field are developing tools for specific applications as the need arises. Most mechanical measurement instruments which are used on the surface can be used underwater, if required.

Some basic tools used to perform certain underwater inspection functions are:

- Liquid Level Indicator. The standard method used by divers to determine the level of liquid in a tank is to sound the boundary by striking it with a hammer. Underwater ultrasonics can also be used to determine the liquid level in a ship's tank that is bounded by the skin of the ship.

- Fouling Level Indicators/Instruments. There are no fouling level indicators in existence to replace visual examination. Standards for measuring fouling have not been determined. Most laboratory experiments that seek to measure fouling level use foulant weight as an indicator. This is a simple measurement for a test plate but is impractical for shipboard use.

- Profilometers. In order to measure roughness or profile, the Navy diver presently uses a template and feeler gauges. This template may be shaped to fit the expected contour, but most of the time it is just a straight surface.

  Other methods exist for measuring roughness but they are not in general underwater use. In one experiment, a mold was made of the surface in question for further laboratory study. However, divers frequently use putty or dough to take an impression of a small area.

C.3.9 Underwater Body Hull Inspections (Cont'd)

Profilometers exist but are not presently used by U.S. Navy divers. In England, roughness is generally measured with ship in dry dock using the British Ship Research Association (BSRA) gauge. This profilometer utilizes a track with a gauge length of 760 mm (30") clamped magnetically to the ship and a measuring head which is rolled along it. A pointer follows the surface of the ship and a trace is produced mechanically on a glass slide.[10]

- Leak Detection. No Navy approved underwater leak detection instruments exist. Leaks in ships' hulls are now detected visually. If the tank or space can be pumped dry, the internal surface is visually inspected for signs of seawater. In the case of a tank, air pressure can be introduced at slightly above external water pressure and the external boundaries can be visually inspected for signs of air or the tank fluid. A dye may be added to the leaking tank to assist in visual location.

  Sonic leak detection instruments are available for dry environment use. These detectors measure the noise produced by air entering or leaving the leak. The extent of use of these instruments underwater is not known. Acoustic emission analysis, non-destructive testing technology, called 'NDT - Acoustics' by Exxon Nuclear, is being applied for the qualification of industrial structures. With this method, the integrity of the entire boundary of a pressure containment system can be evaluated accurately and rapidly requiring only limited access for attaching transducers. This method has been used underwater.[11]

- Corrosion Measurement. No shipboard corrosion indicators exist; however, instruments are widely used in industry to

C.3.9 Underwater Body Hull Inspections (Cont'd)

measure corrosion rates. These instruments generally utilize a small cylindrical rod of the metal under examination. This test electrode does not take into account the ratio of anode area to cathode area existing on a ship inducing galvanic corrosion, nor does it take into account the effects of hull coating deterioration.[12] Therefore, as presently designed, these instruments have no application to large scale hull corrosion measurement. However, the Morgan 'Rust Reader' will give an indication of local potential for analysis by corrosion engineers at a later time. This instrument has potential for ship corrosion measuring.[13] In addition to determining uniform or general hull corrosion/erosion, it is necessary to be able to measure the depth of localized corrosion (pits). A few pit depth gauges are currently in use. The Civil Engineering Laboratory (CEL) Port Hueneme, California, uses a reverse reading micrometer type of pit depth gauge. The pit depth gauge manufactured by W.R. Thorpe & Co. Tulsa, Oklahoma, operates on the same principle. However, measurement of the combined effect of uniform corrosion and localized corrosion, which is generally the case, is of more significance. This determination is currently best performed by measuring the hull thickness from 'inside to outside' by such means as ultrasonics.

- Coating Evaluation Tools. There are no known methods or tools available to the U.S. Navy for inspection of the condition of the underbody hull coating. As a result, the diver can only report when corrosion, discolored paint, or the absence of paint is observed. The commercial ship industry does not have any methods or tools specifically dedicated to the evaluation of coatings by divers. Since merchant ships are still routinely docked at about 2 year intervals, they do not require diver inspection of coating adequacy.

Magnetic paint thickness gauges are available and suitable for underwater paint thickness measurements because the sensor can be separated from the readout instrument. Reference 14 contains a study of tests conducted on various underwater paint thickness meters and recommends a development program.

Non-Destructive Testing (NDT) Equipment

The Navy has promulgated no list of approved NDT equipment. Table 3-6 of Annex C-II lists several NDT equipments manufactured by U.S. companies. These equipments consist of a metal thickness gauge, an eddy current crack detector, and several ultrasonic gauges. The state-of-the-art in application of NDT underwater in the commercial shipping field has advanced over that in the U.S. Navy. Most of this advance has taken place in support of the offshore oil industry. Almost any NDT inspection which can be performed on land can be performed underwater. The major exception is X-ray radiography, which is being replaced by gamma ray radiography.

Equipments are available for magnetic particle (MT), ultrasonic (UT), eddy current, dye penetrant (PT), and gamma radiography (RT) testing.

Most underwater NDT inspection companies make their own adaptation of dry land equipment based on the type of work involved.

Unit Inspection Company of Swansea, England, has provided sales brochures on NDT equipments to be used for:

- Survey of structures and ships' hulls for general damage, cracks, and corrosion

C.3.9 Underwater Body Hull Inspections (Cont'd)

- Inspection of cathodic protection systems
- Examination of marine growth

These equipments include an ultrasonic set, an eddy current meter, and a gamma radiography equipment.

Sylvester Underseas Inspection, a Division of J. G. Sylvester Associates, Inc., Rockland, Mass., a 25 year old land based structural inspection and testing firm, is now offering complete underwater structural inspection and testing services to depths of 600 feet (present capability.)[15] Specific available services are the following:

1. Visual inspection including televised and video recorded inspections and underwater photography of structures, hulls, platforms and the like. They have a patent for a device which enables excellent photography in dirty water environments. Essentially, the device is a membrane which lays against the object being photographed and replaces the dirty water with filtered water. Very large sections can be photographed using this method. They also hold a patent for a flexible, easily portable dry habitat which can be used for dry inspection and repairs underwater. Although this habitat has certain limitations, its portability and ease of use should make it most useful in many situations.

2. Underwater gamma radiography. Gamma radiography is performed using modified conventional land based equipment using special geometric techniques which have evolved from a detailed study and experimentation into the scattering and attenuation effects of water. Underwater radiography may now be performed effectively and routinely to radiographic standards currently used for land based radiography such as MIL-STD-271E or the ASME or AWS Codes.

C.3.9 <u>Underwater Body Hull Inspections</u> (Cont'd)

3. Underwater ultrasonic inspection is now performed with a completely housed submersible ultrasonic unit in which all functions required to conduct the inspection are operable under the water by a highly trained technician/diver. This firm currently has five technician/divers trained as ultrasonic inspectors under the requirements of MIL-STD-410D. The instrument is currently in use on underwater structural inspection of offshore platforms in connection with a Coast Guard inspection contract.

4. Underwater magnetic particle inspection may now be performed routinely and effectively underwater to determine surface and near surface flaws and defects.

5. Evaluation of marine growth, encrustation, and species composition on structures may be performed by a marine biologist.

Much of the commercially available underwater NDT equipment could be purchased off the shelf and used now by Navy technicians while waiting for the formal test and evaluation process. However, it would be preferable for Navy Headquarters to centrally procure equipments in sufficient categories, capabilities, and quantities to provide the full spectrum of NDT capability needed for each inspection activity. This would result in standardization as well as procurement economy of scale.

<u>Boat/Working Platforms</u>

The basic hull husbandry related diver working platform in the Navy is a boat, 35 ft. to 45 ft. long. However, there is no boat of any configuration specified for diver use, much less a designated standard boat. Some commands use 35 ft. to 45 ft. wooden or fiberglass personnel boats, modified by self-help. Other activities utilize 35 ft. aluminum hull boats or boats of other sizes and configurations. Most boats in

C.3.9 <u>Underwater Body Hull Inspections</u> (Cont'd)

use, especially by Afloat Intermediate Maintenance Activities (AD's, AR's, AS's), are inadequate in capacity and configuration to accommodate all of the required hull husbandry diver support equipment. The hull husbandry diver must have a completely outfitted work boat with air supply (both an approved air compressor and a bank of air bottles), fresh-water, welding and other repair equipment, hydraulic and pneumatic power supplies for tools, a warm area for diver to get dry and change clothes, suit storage, and tool lockers. Additionally, the boat must be easily maneuverable and controllable in relatively high wind and current states. The boat should be capable of supporting a minimum of seven divers for at least 16 hours some distance from shore support. A boat meeting these requirements would be in the 40 to 50 ft. length range and would have two engines to provide the required degree of maneuverability and control alongside a ship. The LCM-3, as configured in NAVSEA Drawing No. 145-4777404 Code Ident. 80064, meets these requirements. Only minor modifications would be required to this boat in order to outfit it with the required support equipment. The lifting weight of this boat is less than 50,000 lbs., which allows over 10,000 lbs. of support equipment to be installed before reaching the lifting limit of the AD-37 and subsequent class destroyer tenders, which are equipped with two 30 ton cranes. There are only four AD/AR's remaining in the Active Fleet that do not have a 30 ton lift capability, viz, VULCAN, AJAX, HECTOR, and SIERRA; these ships have a 22-1/2 ton lift capability. It may be determined that a larger boat of greater than 30 ton weight is the optimum size for ashore maintenance activities.

The six Shore Intermediate Maintenance Activities (SIMA's) that will become operational in the early 1980's at Norfolk, Charleston, Mayport, Pearl Harbor, San Diego, and Alameda will assume an increasingly larger share of the hull husbandry program, especially as the older IMA's are decommissioned. Thus, within about 5 years, all AD's will be capable of

C.3.9 Underwater Body Hull Inspections (Cont'd)

lifting 30 ton boats. It is, therefore, fitting that the LCM-3 as configured in the aforementioned NAVSEA drawing become the standard Navy diving boat for at least the afloat IMA's.

Swimmer Propulsion Units

The primary swimmer propulsion unit available in the U.S. is the Rebikoff DR 14 "Pegasus" swimmer propulsion unit. This unit is powered by a 1.3 horsepower motor energized by a 24 volt, 100 ampere-hour battery. It can be fitted with photographic equipment and lighting for use as an inspection vehicle. It can also be used to deliver tools and equipment to divers from their primary support platform. A swimmer propulsion unit is especially valuable where strong currents are encountered, by giving greater physical endurance to its operator diver.

C.3.9.1.1.4 Underwater Hull Location Systems. There are no formal underwater hull location systems in existence, nor are any equipments designated for such use. However, several crude but relatively effective methods of underbody hull swimmer location are used by the diving community. Such methods and other concepts are:

- Keel Hauling Lines. Discussions with numerous divers, both Navy and civilian, indicate that the most widely used device for underwater hull location fixing is the keel hauling line, or hogging line. This line consists of a gunwale to gunwale keel hauling line with a weight (usually about 10 pounds, attached to a free riding pulley) at the center of the line. Using a pair of keel hauling lines in leap-frog fashion, most of the underbody hull can be surveyed with a rough degree of locational accuracy.

- Bottom Search Lines. A variation of the keel hauling line, described in the NOAA Diving Manual,[16] Chapter 7, uses search lines laid out on the bottom by anchors. This method

C.3.9 Underwater Body Hull Inspections (Cont'd)

probably has very limited application in most Navy ports because of the soft mud bottom and water depths.

- Grid Markings. The Royal Navy has experimented with the use of grid markings painted on the underwater hull of at least one ship, with the grid sizes about 10' x 80'. This may result in a minor adverse effect on camouflaging. Long-term evaluation results by the British on this method are not available at this time.

- Net Grid Concept. Consideration might be given to developing a light fishnet type grid which could be supported at the deck margin line and dropped overboard. Major blocks of the net, on the order of 10 foot squares, might be appropriately color coded for major sector location. An intermediate smaller squared network on the order of 2 foot squares would assist the diver inspector in location/mapping of underwater sectors. In order to stabilize the net against the hull, magnets could be installed at junction points of the network for holding the system against the hull. Intermediate points within the smaller net squares could be either estimated or measured with a short tape for more accuracy in mapping.

- Hull Striking by Hammer. Another crude type locational system frequently used to locate specific areas of inspection on the hull consists of a sailor striking the inside hull plating or fitting with a hammer while the swimmer homes in on the sound.

- Acoustic Pingers. Innerspace, Inc. of Dickinson, Texas, has designed an acoustic pinger/receiver system, which they consider to be proprietary. Therefore, information on the design is not available at this time.

C.3.9 Underwater Body Hull Inspections (Cont'd)

- Acoustic Navigation System. NCSL is in the process of developing a "Swimmer Area Navigation System,[17] based on a pair of acoustic transmitters attached on or near the underwater hull of the ship to be inspected. Swimmer location is displayed in X-Y coordinates via LED readouts on the diver held receiver unit, which is neutrally buoyant. This system has a potential location accuracy of about 2 feet or less, depending upon the diver's location relative to the baseline of the two transmitters. Theoretically, use of more than two transmitter pairs arranged in an optimum configuration on the harbor bottom or on an alongside pier would result in a location accuracy measured in inches.

The MARAD Research Center, Galveston, Texas, conducted five TV camera tests in the area of waterborne hull inspections for corrosion damage. The tests indicate that turbid water conditions provide a formidable deterrent to obtaining intelligent definition of hull surface conditions. Hull marking to determine location during inspection was found to be mandatory due to the relatively small field of view of the camera.

C.3.9.1.1.5 Software. This section contains state-of-the-art discussions of diver training and inspection standards and reports.

Diver Training

The success of nearly every aspect of the hull husbandry program is directly related to the qualification and motivation of the personnel conducting inspections of the underwater body and appurtenances of the ship. The current state of training of Navy divers vis-a-vis all aspects of hull husbandry inspections leaves much to be desired.

It may be too much to expect the Navy diver to become a qualified hull integrity inspector. Some commercial companies, particularly in Europe, have made the decision to train ship inspector personnel as divers

C.3.9 Underwater Body Hull Inspection (Cont'd)

rather than vice versa. It is questionable, however, whether a qualified inspector who normally works in an outside, drydock environment would be comfortable as a diver, if he was even inclined to want to dive in order to do his job.

The hull seaworthiness inspection is a highly specialized field, and it normally takes a relatively large amount of field experience to train a good inspector. Most of the highly qualified hull inspectors in the maritime field either grew up in the profession or came from U.S. Coast Guard billets. They are generally older than the average Navy diver.

In order to provide the Navy with underwater inspection capability, it is necessary to develop a program for training the personnel to conduct the inspections. If sailors are to be trained for this task, those personnel selected should be divers with hull, deck, or machinery rates. The divers should be given a course in what to expect when under a ship while conducting an inspection and what to look for. The Underwater Work Techniques Manual, upgraded as required, should be utilized as the best available textbook. After completing this course, the diver/inspector should conduct an underwater inspection of a ship which is drydocked.

The diver/inspector should accompany and observe a shipyard hull inspector during a regular drydock inspection. The diver should assure himself that he has covered all of the items which a hull inspection entails. This process may take several weeks.

Next, the diver/inspector should make another inspection of a waterborne ship and submit a written report of his findings to his supervisor. This inspection should also be of a ship which is scheduled for drydocking. The supervisor should compare the inspection report with the drydock findings and grade the inspector. Three satisfactory predrydock inspections would probably be required before the diver is certified as an underwater hull diver/inspector.

C.3.9 Underwater Body Hull Inspections (Cont'd)

Critiquing of individual and team efforts should be a routine procedure in this training program. Specially designed short tests should be developed to assist trainees in determining their assimilation of information and assist supervisory inspectors in evaluating individual trainee progress as well as the effectiveness of the training program, weaknesses, and the need for improvements in material used, techniques employed, etc.

Some commercial operations, as well as many Navy UDATS users, station their most knowledgable hull inspector topside to monitor and direct the diver through the UDATS video monitor and communication circuit. This enables the inspector to view areas of interest at will as well as to query the diver as to what his eyes and sense of touch tell him of the condition of the area being inspected. Training for both inspector and diver in this team mode is needed on a high priority basis.

Inspection Standards

The Hull Husbandry Work Shop discussed the problem of inspection standards in many work groups. In every case, the lack of inspection standards or procedures was such that the diver was concerned over the results of his inspection. The Underwater Work Techniques Manual is the basic reference for diver inspections; however, it does not contain standards for inspector use.

In most underwater inspections the diver is told only to inspect and report the condition found. Standards for evaluation of these observations are not provided. This sometimes results in divers not recognizing defects which exist. Commerical concerns are encountering similar problems. Some firms are considering training inspectors and surveyors as divers in order to eliminate this problem.

The following excerpt from a commerical inspection form for pre-sea trial inspections indicates one aspect of the inspection problem.

C.3.9 Underwater Body Hull Inspections (Cont'd)

"Acceptance/rejection of the Sea Chest Proper shall be based on the diver's judgment of whether or not the existing conditions will cause a flow restriction which would interfere with operation. If, in the opinion of the diver, excessive interference will occur, sufficient cleaning shall be accomplished to correct the condition."

Such direction makes the diver responsible for performance of the ship's system. In most cases, divers would probably clean the sea chest whether required or not, just to be safe.

In inspecting for hull fouling, a diver must rely on his own judgment, as no standards exist. Fouling is usually reported in subjective terms such as light, medium, heavy, patchy, or scattered. Part 5, Section 3, of the Underwater Work Techniques Manual provides no guidance for inspection of fouling conditions. This manual, for many areas of the hull, tells the diver what to look for, but does not identify what is acceptable and what is not acceptable.

Afloat inspection requirements for submarine sonar domes are treated in considerable detail in Sonar Dome Handbook, Volume V, Submarine Sonar Domes, NAVSEA 0967-412-3050. Recent correspondence between Commander, Naval Sea Systems Command (SEA-06H4) and Commander, Navy Ship Engineering Center on the subject of submarine sonar dome maintenance indicates a high level of interest and appreciation in the development of inspection criteria for fouling and paint thickness, cleaning techniques between overhauls to extend antifouling life, and criteria for frequency of cleaning. Results of this development are to be incorporated into a revision of the Sonar Dome Handbook.

Sonar Dome Handbooks, Volumes I through IV (for Surface Ships) NAVSEA 0967-412-3010, 3020, 3030, and 3040, respectively, give scant treatment to surface ship sonar dome afloat inspection requirements or procedures.

C.3.9 Underwater Body Hull Inspections (Cont'd)

It is worthy of note that the MARAD Research Center Galveston has proposed development of an underwater hull integrity/seaworthiness program involving a 5 year effort. It is considered that such a program can be developed in a significantly shorter period than 5 years.

Inspection Reports

The Underwater Work Techniques Manual contains a suggested report form for use by divers reporting results of underwater inspections. This form lists the many areas to be checked during this inspection.

A review of report forms being utilized by five Navy diving activities revealed that not all of the items listed on the suggested report form were being inspected. This indicates that most activities are not conducting inspections to the degree of thoroughness expected by the requestor. The quality of the inspections varies significantly from activity to activity. It is standard practice to provide inspection reports to the ship's commanding officer only. Copies are not provided to other activities for analysis of the information reported.

C.3.9.1.2 Fixed, Mobile, and Remote Controlled Underwater Inspection Systems and Concepts. Inspection equipment discussed so far have related to diver use only. A few equipments in use or under development that apply to the underwater inspection of ships do not rely upon the use of a diver. Other concepts also exist that may result in cost-effective methods of conducting underwater hull inspections and other hull husbandry related functions. These systems and concepts are arbitrarily defined herein as being either fixed, mobile, or remote controlled inspection facilities. Many of these facilities are designed to allow a trained hull inspector to observe the condition of the underwater body close-up in a dry environment.

A fixed inspection system is defined as a designated location which contains fixed facilities either for viewing the underwater hull of a ship or for controlling the movement of an enclosed underwater inspection vehicle. A mobile inspection system is defined as an inspection vehicle which may be attached to a fixed facility but which can be moved from location to location. A remote controlled inspection system is one that is controlled by an inspector who is not at the actual inspection site.

All fixed, mobile, and remote controlled inspection facilities either require water with good visibility or need to incorporate high quality clear viewing devices if the primary sensor is the human eye or TV/photographic equipments.

Fixed Inspection Facility Concepts

Specially designed, fixed inspection facilities have the potential of being less labor intensive, hence likely more cost-effective, than other types of inspection systems, at least for some inspection purposes. The determination of the condition of hull coatings and the extent of fouling, for example, may be effectively accomplished by one or more sensor/observation systems based on principles to be discussed later, that would be compatible with a fixed facility. One such facility concept would involve the installation of track system, parallel to the keel line of a ship alongside, mounted on the face of a pier. On this track, which may be either above or below the water surface, a vehicle would operate on which would be mounted the inspection head or array. The vehicle with inspection array attached would observe and record the condition of the hull from waterline to keel and from bow to stern in a relatively few passes. The inspection head or array would employ equipment operating on one or more of the following principles:

C.3.9 Underwater Body Hull Inspections (Cont'd)

- TV or Photography: B&W, Color, and Stereoscopic. Underwater TV and photography enjoy wide commercial usage; however, most of this takes place in very clear water conditions, usually tropical or subtropical which affords good natural light. For the turbid waters of Navy ports, significant effort in increasing the visible range of these systems is required to improve the quality of the image and increase inspection rates. Effort toward optimizing the type of lighting system, e.g., thallium iodide, mercury vapor, quartz iodide, stroboscopic, etc., is needed, as are improvements and standardization of clear viewing attachments to TV/photographic cameras. Stereoscopic photography has been used on a limited scale for underwater work (NCSL has conducted some tests in this area). Stereophotographs can also be obtained with a single camera by taking a sequence of photographs, with the camera undergoing a small displacement between exposures. Sequential images are readily produced if the camera is mounted on a stable platform traveling at a uniform speed. A simple intervalometer can be used to trigger the camera at fixed time intervals, corresponding to the desired constant displacements of viewing position. The principal use of stereo would be to better determine the extent, types, and depths of fouling on the hull.

- IR Heat Sensors. The concept of using an IR heat sensor to determine the extent of hull fouling, based on the insulating properties of the foulant, should be examined.

C.3.9 Underwater Body Hull Inspections (Cont'd)

- Reflectometer. The measurement of light reflected or scattered by a surface may provide a useful indication of the degree of roughness of the surface. Hull resistance, whether resulting from fouling or from rough substrate or coating surface, causes increased power requirements. It is, therefore, necessary to know the maximum degree of actual hull/coating roughness that can be tolerated. This is particularly true for sonar domes and propellers. The use of reflectometers to measure roughness may prove to be a valuable diagnostic tool.

- Acoustic Holography (Sonoptography). Inasmuch as the specific acoustic impedence of most hull foulants is very nearly that of water, the use of acoustics to detect fouling is very unlikely. However, acoustic holography, which is still in its infancy, may prove effective in determining the extent of fouling that exists on a ship's hull.

The location of a fixed inspection facility based on the foregoing concepts should be in water having the best possible visibility. One such facility in each of the three major ports in each Fleet may be unaffordable, in which case one such facility in each Fleet should be considered.

Possible fixed inspection facilities include:

- A graving dock-like facility. This would be essentially a dry dock filled with clear (filtered or treated) seawater except that ships would remain afloat while being inspected. This facility may be cost-effective only where an unused dry dock exists, which is not a likely situation. However, the feasibility of this concept should be studied.

C.3.9 Underwater Body Hull Inspections (Cont'd)

- A mooring berth, either pier or anchorage, in very clear and undisturbed water. For example, the pier at U.S. Naval Station, Roosevelt Roads, Puerto Rico, is located in very clear, undisturbed water over a sandy coral bottom. Divers could, at this moment, conduct reasonably thorough inspections of the underwater hull of ships with currently available equipment. The maximum utilization of this pier should be realized by all ships operating in or passing through that area. Divers and UDATS equipment can readily be flown to Roosevelt Roads from most any U.S. Navy operating port having divers, if it is not considered cost-effective to have them stationed there.

A similarly beneficially endowed mooring may be available to the Pacific Fleet—perhaps a pier at San Clemente Island exists suitable for this purpose. In any event, for the immediate future, as many locations as possible should be identified (and used) that would provide an environment suitable for conducting acceptable underwater inspections.

- Afloat Docking Concept. A unique containment floating dock can be employed to avoid environmental contamination, and which may be helpful in minimizing visual interference in connection with hull inspection afloat. The system consists of a large plastic envelope which normally lies on the harbor bottom. After positioning a vessel over the submerged "bag," the peripheral boundary of the bag is inflated, causing the boundary to rise to the surface, forming a giant flooded enclosure about the hull, with the boundary "ring" surrounding the ship at the waterline. This "wet dock" minimizes water sedimentation activity about the underbody of the vessel, keeps floating debris

C.3.9 Underwater Body Hull Inspections (Cont'd)

away from the hull, and similarly precludes waste matter or cleaning matter from moving into the surrounding marine environment. It would be possible to circulate clear/ freshwater into this "dock" area and remove sedimentary water to some degree, providing a more desirable working environment in the vicinity of the hull for inspection or working.

This concept needs further research and development to determine design criteria and effectiveness/applicability to the program.

There are no fixed underwater inspection facilities in existence today.

Mobile Underwater Inspection Systems

Naval Undersea Center (NUC), San Diego, has been involved in the design and development of four specialized submersibles which, conceptually, could have application to the underwater hull inspection portion of the hull husbandry program.

The first three, NEMO, NAKAKAI, and DEEPVIEW, are evolutions in a family of vehicles with relatively similar characteristics. Each vehicle is only a means for visual observation, though TV cameras could be added. NEMO was the first vehicle in the family and was the first to use an acrylic sphere at depth. MAKAKAI was larger and again used acrylic, while DEEPVIEW used a glass and steel pressure hull with an acrylic aperture. All three vehicles are basically observation platforms, with a self-powered, untethered capability and an operational depth of 600 feet. The vehicles have a far greater potential range of usage than would be necessary in the hull observation task which should not require more than a 60-foot operating depth capability. The added depth capability in this family would increase cost substantially with no equivalent added payoff for the tasks being envisioned for the current project. Each of these vehicles was built as a single prototype and costs are not available. A practical conclusion can easily be reached that this family has far more capability than is necessary for the task in mind here and certainly would not be cost-competitive with alternate methods for accomplishing underwater hull inspections. Future efforts at NUC in the NEMO family area are pointed toward development of working tools and attachments.

The fourth vehicle, Hull Inspection Platform (HIP) is a mobile vehicle that is radically different from the NEMO vehicles. The platform consists of a self-propelled catamaran hull with hydraulic crane attached. Mounted on the outboard end of the crane is a capsule capable of supporting an observer in a shirt-sleeve environment. The capsule is lowered into the water and provides a movable platform for the inspection of ships' hulls. The boom can be controlled from the hull or from the capsule.

When deployed, HIP will allow a person without diver qualifications to inspect a medium-size ship in less than one day even in waters that are relatively murky and infested with hostile sea life. Because the observer is at atmospheric pressure, none of the support personnel generally needed for scuba or hard-hat diving operations will be required. The functionally designed HIP may require only a crew of three for performance of the hull inspections. Two of the crew members would remain on deck while the observer is performing the actual inspection.

In addition to the primary function of hull inspection, the underwater capsule and hydraulic arm subsystems could be equipped with an array of tools for hull-bottom maintenance operations currently performed by divers. For example, inspection and cleaning of specific hull regions or fittings with various types of devices appears feasible.

C.3.9 Underwater Body Hull Inspections (Cont'd)

The limiting factors in the use of the current version are the 36-foot length of the boom and the lack of angular rotation of the observers station. The latter would be a definite requirement if an observer is to examine the underside of the flat sections of a hull. As presently configured, the observer's seat does not rotate, is too narrow to use gimbals, and is limited to side observations only. Extensive re-engineering would be required for an observer to be able to inspect the flat bottom of a ship.

HIP is currently in a dismantled state at the NUC Laboratory in Hawaii. It has been man certified, with operational procedures and safety precautions written. There are no known future plans for HIP. The limitations in the HIP vehicle as presently configured are too extensive to make this system a viable candidate. However, it represents a valid inspection platform concept.

Another mobile system for underwater inspection existed at one time. This system consisted of a floating obervation box which was connected to an underwater device by fiber optics. The underwater device was positioned against the area to be inspected by a diver. Lighting was transmitted through the fiber optic cable. The present status of this device is unknown.

Remote Controlled Inspection Systems.

Remote control inspection vehicles are becoming more abundant as the need for information on underseas pipelines and cables increases. Most of these remote vehicles are designed and constructed to perform specific missions and are of little value as hull inspection tools; however, the concepts employed must be analyzed to determine the concept applicability for underwater hull inspection vehicles.

Table 3-7 of Annex C-II is a listing, with basic characteristics, of five remote controlled inspection systems in use by industry. All

C.3.9 <u>Underwater Body Hull Inspections</u> (Cont'd)

five systems utilize, among other equipments, a TV system. The U.S. Navy has no remote controlled underwater inspection systems. The only system listed that is used for the inspection of ships' hulls is SCAN which is employed by the Underwater Maintenance Company, Ltd., of Southampton, England, at their Las Palmas, Canary Islands, "wet dock" ship maintenance facility. This system has two specific limitations (not mentioned in Annex C-II) which were reported in correspondence from the Company. First, because the SCAN system is remotely operated and has positive buoyancy, it is effective only on the flat bottom section of the underwater hull portion of ship. Second, water visibility is a very limiting factor in the use of SCAN. The waters in Las Palmas harbor are approximately an order of magnitude less turbid than the waters in the majority of U.S. Navy ports. Therefore, SCAN as presently configured would have limited application in the overall U.S. Navy hull husbandry program.

One SCAN TV camera looks forward at a shallow oblique angle to display a large trapezoidal area. The second TV camera and the photographic camera are set at almost right angles to the hull in order to show a smaller area in close up. The control console enables the operator to vary lighting, focus, pan, and vehicle movement. The console operator also controls the 35 mm camera shutter.

SCAN was designed to supplement diver inspection of the ship and to cover the large flat expanse of a ULCC bottom. Its applicability to most Naval ship hull forms is doubtful, although carriers, tankers, landing ships, and ammunition ships have large flat bottoms. A similar vehicle could be developed for Naval ships if it can be improved and reconfigured so as to be effective in turbid waters and for use on sides of ships.

C.3.9 Underwater Body Hull Inspections (Cont'd)

C.3.9.2 Technology Gaps. The basic technology gaps in the area of Navy underwater hull inspection relate largely to the lack of application of existing commercially available equipment. The following categories are representative:

- NDT Equipment
  - Wet magnetic particle
  - Ultrasonic
  - Eddy Current
  - Gamma radiography
- Low light level and color TV
- Clear field viewing devices
- Photography, including stereoscopic

It is not intended to give the impression that all of the above-listed equipments are pushing the technological state-of-the-art. Considerable effort is still needed in redesigning and refining these and other equipments to make them more effective for Navy underwater use. Human factors engineering as well as ocean engineering disciplines need to be applied to the development process.

C.3.9.3 Needed RDT&E. The need for basic research is minimal, as many equipments and systems relating to underwater hull inspections exist in the commercial and off-shore communities. What are needed the most, and at high priority, are test and evaluation of commercially available inspection tools and equipments and the development of underwater hull inspection software, e.g., standardized inspection procedures and reports, and diver training.

Concepts, equipments, and systems requiring RDT&E efforts are discussed in three categories (Basic Research, Development, and Test and Evaluation) below:

C.3.9 Underwater Body Hull Inspections (Cont'd)

- Basic Research. Research effort is needed to develop measurement instruments for the following functions:

  - Liquid level
  - Fouling levels
  - Surface roughness/profiling
  - Leak detection
  - Corrosion rates
  - Coating degradation and coating effectiveness

  Basic research is also needed to explore more concepts for underwater hull location application. Accurate location fixing is essential to an effective underwater hull inspection system. Techniques or devices that can be designed into the ship's hull should be explored in depth, as should portable devices for application on ships currently afloat.

  Research in design, materials, and fabrication of mini-docks and cofferdams for inspection and repair purposes should be pursued.

- Developmental Effort. A significant developmental effort is needed to adapt and refine many equipments, tools, and techniques that exist in various forms in both commercial and Navy application. Further developmental work is needed in the following areas:

  - Clear field viewing devices both for inspector use and for attachment to TV/photographic systems

C.3.9 Underwater Body Hull Inspections (Cont'd)

- Hull Inspection Platform (HIP) prototype built by NUC, San Diego, needs greater positioning capability, improved visibility for inspector, and incorporation of manipulator arm
- Diver face mask which does not restrict visibility

Perhaps the most significant developmental effort needed is that relating to inspection software as described below:

- Develop standard inspection and diagnostic procedures
- Standardize terminology for reporting
- Develop standardized reports
- Develop training program for Inspector/Diver Teams
- Develop standard inventory of support equipment
- Develop fouling diagnostic inspection criteria
- Develop classifications and descriptions of foulants and incorporate into diver training.

• Test and Evaluation. At present, there are many inspection-related equipments available on the commercial market and in use by the offshore and maritime industries that are suitable for Navy underwater hull inspection purposes. Most of these equipments can be used at this time by Navy divers; however, for the long-term benefit of the program, a test and evaluation effort should be undertaken on these so as to ensure optimum characteristics and standardization. It is essential that equipments designed for underwater use be optimized as to size, weight, shape, color, etc., keeping in mind the man-machine interface in the development process. The following equipments fall into this category:

C.3.9 Underwater Body Hull Inspections (Cont'd)

- TV (both B&W and color) and still photography including stereoscopic systems
- NDT equipment
  - Ultrasonic devices
  - Gamma radiography devices
  - Wet magnetic particle inspection devices
  - Eddy current equipment
- Swimmer propulsion units to increase swimmer effectiveness in currents

In addition to the foregoing, it is desirable to conduct feasibility studies in the following areas:

- To match commercially available underwater TV components such as lights and cameras with existing UDATS.
- To standardize component interfaces of TV systems to match developing add-ons.
- To determine effectiveness of and need for fixed underwater hull inspection facilities, such as graving docks and specially configured piers.

C.3.9.4 Environmental Considerations. The effect on the environment of equipments, systems, and procedures relating to underwater hull inspections at the present, and well into the foreseeable future, is negligible. However, it is the environment (turbid water, currents, foulants, etc.) that imposes the greatest constraint on the development of an underwater hull husbandry program.

C.3.9.5 Personnel Considerations. Personnel factors account for some of the greatest constraints on an underwater hull inspection program.

C.3.9 Underwater Body Hull Inspections (Cont'd)

The human being is the key to all aspects of the inspection process from observer (diver) to topside decisionmaker. Training of all key personnel is the foundation of the program. It is outside the scope of this study to determine the optimum mix of divers, observers, and inspectors and their specific functions. However, if Navy divers do all underwater inspections using UDATS and other available equipments, whether for fouling diagnostic purposes or for hull integrity/seaworthiness purposes, the present manning allowance of divers is insufficient. The total number of divers needed in the hull husbandry program will be driven by the number required for the underwater cleaning function. Therefore, total numbers are not addressed in this appendix. On the other hand, if hull integrity inspections are conducted by personnel from the Navy Shipyards' QA Inspection Division, a significant increase in numbers of these personnel will be needed. It is doubtful, because of age, motivation, and Civil Service position description guidelines, that a sufficient number of shipyard QA hull inspectors will ever be available as underwater hull inspectors. Thus, for the near future the most workable solution is to utilize Navy divers, after intensive training, as the UDATS vehicle, and utilize trained hull inspectors on the UDATS TV monitor topside. This would require special team training as well as individual training for each principal involved. In any event, more Navy divers and more hull inspectors are needed than now exist.

C.3.9.6 Equipment Support. It is difficult in discussing a subject as broad as underwater hull inspections to isolate for evaluation one topic such as "equipment support." Equipment support will vary considerably between the modes or methods of inspection to be selected. However, the most extensive support required relates to the use of divers as the primary inspection element. The basic equipment support relates primarily to tools, a standard fully equipped boat, and life support equipment, which have been discussed earlier in the state-of-the-art section and will not be repeated here.

C.3.9 Underwater Body Hull Inspections (Cont'd)

C.3.9.7 Effectiveness Evaluation Plans. The development of effectiveness evaluation plans for underwater hull inspection methods cannot be addressed until the methods to be employed have been decided upon. However, an approach to effectiveness evaluation would be to conduct a controlled test whereby a ship was inspected separately and serially by several teams utilizing different inspection equipments and procedures. Accurate documentation of hard copy and video-audio tape would be obtained on each inspection. The ship would then be drydocked and all parties involved would reinspect the ship, a critique would be held by a "senior inspector," and the results compared.

This type of comparative evaluation will provide the best short-term evaluation of the inspection methods to be employed. It is proposed that effectiveness evaluation of individual equipments and tools involved in underwater hull inspections be performed by NCSL as an ongoing effort assisted by specially designated Fleet introduction units, one each in the Atlantic Fleet and Pacific Fleet.

C.3.9.8 Development Progress Tracking Plans. The tracking of underwater hull inspection research and development effort worldwide is necessary to ensure that the U.S. Navy has the most cost-effective equipments and tools that technology can provide. Discussion of such a broad topic is best done at a much higher topic level than here. Therefore, this topic has been elevated to a higher element in the study and is addressed in Section C.2.2.5.

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ANNEX C-I

TORSIONMETER STATE-OF-THE-ART

TORSIONMETER STATE-OF-THE-ART

The current survey of six manufacturers represents a comprehensive effort to determine a cost-effective device for shipboard diagnosis of hull/propeller fouling. The data which follows includes a brief description of the operating principles of each device and a comparison matrix (Table 1) of data accumulated. The operating principle descriptions are arranged alphabetically by manufacturer. The final page contains a complete mailing address for each manufacturer within the survey. The manufacturers included were:

Acurex Corporation

Galbraith-Pilot Marine Corporation

The Indikon Company, Inc.

Mechanical Technology, Inc.

Simmonds-Precision

Ultra Products Systems, Inc.

Two additional manufacturers were contacted. McNab Inc. (New York) produces a horsepower meter practically identical to the Galbraith-Pilot device. Since McNab represents no significant technological difference from the Galbraith-Pilot device, it was not directly included in the survey. Jungner Instrument AB (Sweden) manufactures a torsionmeter similar to the Simmonds-Precision device. Operation involves two clamp-on gears, one mounted directly to the propeller shaft, the second attached to a cantilever sleeve. Shaft twist is measured by transducers which physically contact the rotating gear teeth. Since Jungner Instrument represents foreign manufacture of a device similar to a U.S. product, it was not included in the survey.

A signal proportional to shaft twist is measured via a hermetically sealed strain gage bridge mounted on a bending beam. The bending beam is supported between two clamping rings installed on the propeller shaft approximately 18 inches apart. Power to drive the rotating electronics and strain gage bridge is provided by a rotary transformer. The bridge output signal is modulated and transmitted to a stationary antenna by a low power transmitter. The torque signal is then demodulated and made available for display.

Shaft speed is determined from the measurement of the period of shaft rotation, obtained from timing pulses generated from a metal trigger attached to the sensor. Ship speed is calculated from the period by analog means.

Shaft horsepower is calculated from the torque and speed information by an analog circuit.

Typically, installation of the precalibrated device is accomplished aboard ship with the zero adjustment made by drag shaft operation of the plant.

A signal proportional to shaft twist is measured via a linear variable differential transformer (LVDT) attached to a rotating husk assembly clamped to the propeller shaft. The husk assembly consists of two cylindrical portions clamped to the propeller shaft at their outer ends and capable of independent rotation resulting from the shaft twist between the clamping points. The LVDT core is attached to one portion of the husk while the transformer windings are attached to the second portion. Thus shaft twist causes displacement of the core within the windings and generates a signal proportional to shaft torque. Power to the rotating husk and the torque signal generated by the husk are transferred by a brush and slip ring assembly.

A direct current signal representative of shaft speed is provided by a tachometer generator mechanically coupled to the shaft via the husk.

Shaft horsepower is computed from the torque and speed information by an analog circuit.

Installation of the device is readily handled aboard ship with zero adjustment by drag shaft operation of the propulsion plant.

A signal proportional to shaft torque is measured via a strain gage bridge bonded directly to the rotating propeller shaft. Power to the bridge and torque signals from it are transmitted through rotary transformers. An internal self-calibration procedure periodically unbalances the strain gage bridge to produce a precise calibration voltage. The calibration voltage and torque signal are both processed by the same electronics providing a continuous recalibration of the bridge during operation.

Shaft speed is measured by a proximity probe using marks on the shaft.

Shaft horsepower is computed from the torque and speed information by an analog circuit.

Installation may be accomplished aboard ship but is better handled by the manufacturer at the factory. Permanent factory installation on an existing shaft coupling or a replacement coupling eliminates need for change in the torsional stiffness of the drive train. No zero adjustment aboard ship is required.

A signal proportional to shaft twist is measured by magnetostrictive techniques. Three rings of laminated steel poles contained within the cylindrical sensor completely surround the propeller shaft. For ease of installation the sensor is composed of two halves bolted together mounted concentric to the shafting and supported by the ships structure. The middle ring, displaced a half pole pitch in relation to the outer rings, provides the primary excitation of the device. Tension or compression in steel affects its ability to carry magnetic flux when subjected to a magnetic field. The outer rings of poles sense this change in the magnetic characteristics of the steel due to torsional loading of the shaft. There is no physical contact with the shaft.

No shaft speed measurements or horsepower calculations are made.

Installation of the device aboard ship requires full scale calibration using a secondary torsionmeter and zero adjustment using drag shaft techniques.

Simmonds Precision

A signal proportional to shaft twist is measured from the phase difference in signals generated by the magnetic teeth of three gears spaced an equal distance apart. The torque gear is mounted directly to the shaft while the reference (center) gear and position gear are mounted to a reference sleeve. As the shaft rotates a three pole electromagnetic transducer senses the relative position of the gear teeth, generating three voltages whose frequency is proportional to shaft speed. The phase displacement between the torque and reference gears is proportional to shaft twist. Variations other than shaft twist generate phase displacements with respect to the position gear, these phase shifts are used to eliminate the errors caused by the other shaft variations. In addition the reference sleeve is clamped to the shaft in a cantilever fashion allowing the gears to be placed close together while sensing shaft twist over a more significant distance.

Shaft speed is determined from the number of teeth passing the sensor per minute.

Shaft horsepower is calculated from the torque and speed information by an analog circuit.

Permanent factory installation on an existing shaft coupling or replacement coupling design eliminates the need for changes in the torsional stiffness of the shafting or major shafting modifications. A clamp-on model is available from the manufacturer for temporary installation or when no shafting redesign is permitted. No shipboard zero adjustment is required.

A signal proportional to shaft twist is measured from the phase difference in signals recorded on hermetically sealed magnetic tapes bonded concentric to the shaft at two points along its length. Recording and reading of the magnetic tapes is accomplished by inductive read/write heads similar to those used in computer tape systems. Recording is accomplished by low speed turning (about 20% of full scale speed) under no load conditions or during drag shaft operation. The noncontacting magnetic heads are rididly mounted adjacent to the shaft with separation of the signal tapes as small as twice the shafting diameter. No power transmission to or electrical signal extraction from the rotating equipment (other than the magnetic signals on the tapes) is required.

Shaft speed is measured using the frequency of the sensed signal from one of the magnetic heads.

Shaft horsepower is computed from the torque and speed information by an analog circuit.

Installation aboard ship involves the bonding of the magnetic tapes to the shaft surface and encoding tapes using the installed magnetic heads. The magnetic tapes may be installed on each side of a bearing housing providing a stable mounting point.

Comparison Factors for Table 1

The factors listed in Table 1 are defined as follows:

Principle of Operation - brief description of method employed to sense shaft torque

Shaft Contact - brief description of required physical contact with the shaft

Cost/Shaft - Budgetary estimate in 1976 prices of currently available devices on a per shaft basis, not including installation. For nonmilitarized designs, the cost of available commercial devices is given.

Current Military Use - Currently in use in NAVY test and evaluation programs (NTE), aboard NAVY ships (NAVY) or aboard Coast Guard Ships (CG)

Installation Time - Approximate number of man-hours required by manufacturer's representative or qualified shipboard personnel to perform sensor and electronics installation. Estimate does not include time required to pull cables, to prepare bed plate or mounting devices or to perform drag shaft zero adjustment since these times are highly unpredictable.

Calibration - specifies factory precalibrated or method of shipboard calibration

Zero Adjustment - specifies method of shipboard zero adjustment if required

Accuracy - electronic test point accuracy in percent of full scale for shaft horsepower, shaft torque and shaft speed. The ability or inability to measure torque at zero speed is noted.

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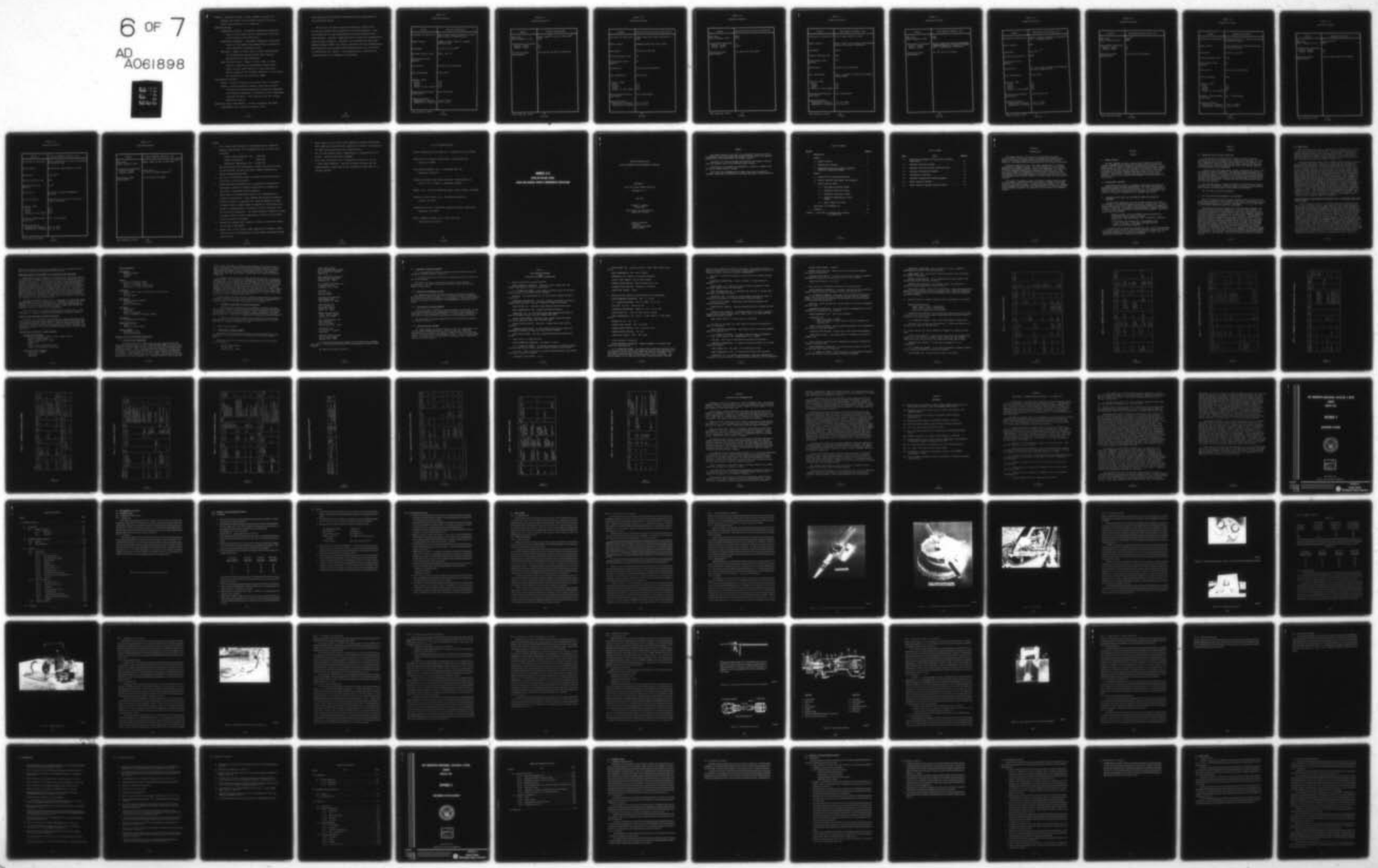

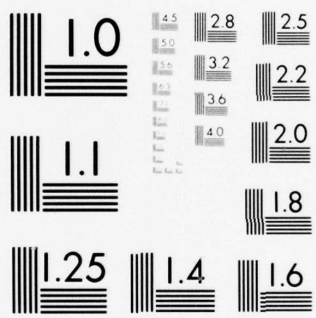

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Display - parameters (power, torque, speed) available for display and whether current models display these parameters simultaneously or by selection.

Operating Ranges

Temperature (Sensor) - acceptable temperature operating range for the sensor and its associated electronics to be mounted in the shaft alley

Temperature (Display) - acceptable temperature operating range for the display and computational electronics to be mounted in a habitable area

RPM Limit - Upper or lower limit to shaft speed imposed for technological reasons which might restrict applicability to ship propulsion

Shaft Diameter Limit - Upper or lower limit to shaft diameter imposed for technological reasons which might restrict applicability to ship propulsion. Meters capable of the diameter range of 7 to 40 inches are indicated as not restricted (NONE).

Installation Clearance

Length - Length of shafting over which twist is measured

Radius - Distance measured radially from shaft surface including the maximum dimension of rotating components and telemetry equipment or electronics which completely surround the shaft. This distance does not include protective covers.

Electrical Power Requirements - voltage, frequency and power requirements for currently available units

Items denoted as NA indicate information was not applicable to the particular device.

The ability to measure torque or horsepower within about one percent appears quite adequate for fouling diagnosis. Long term stability and good repeatability are more important than true accuracy. However, comparison data on drift and repeatability often was not available. Similarly no information on mean time between failure (MTBF) was readily available from all manufacturers. When MTBF data was available good documentation as to its method of computation was lacking. Thus repeatability, stability and reliability were not compared in the matrix.

Table 1,a

Comparison Matrix

Factor	Acurex Corporation
Principle of Operation	Rectilinear motion sensed by strain gage bridge on bending beam
Shaft Contact	Clamp-on metal rings to support bending beam
Cost/Shaft	$13,000 to $15,000[a*]
Current Military Use	NAVY, NTE, CG
Installation Time Man-hrs	4
Calibration	Factory pre-calibrated
Zero Adjustment	Drag shaft
Accuracy (%FS)	
Power	1.25
Torque	1.0
Speed	0.25
Torque at zero speed	Yes
Display, Simultaneous/ Selectable	All, selectable
Operating Ranges	
Temperature (Sensor)	-5°C to 65°C
Temperature (Display)	10°C to 50°C

*See notes pp. 23-24

Table 1,a

Comparison Matrix

Factor	Acurex Corporation
RPM limit	Above 10%FS[f]* to max of 1000 rpm[g]*
Shaft Diameter Limit	None
Installation Clearance	
Radius, inches	6"
Length, inches	18"
Electrical Power Requirements	115/230 VAC 50-400 Hz 200 Watts

*See notes pp. 23-24

Table 1,b

Comparison Matrix

Factor	Galbraith-Pilot Marine Corporation
Principle of Operation	Linear motion by LVDT attached to husk
Shaft Contact	Clamp-on husk with slip rings
Cost/Shaft	$12,000 to $15,000
Current Military Use	CG
Installation Time Man-hrs	16
Calibration	Factory pre-calibrated
Zero Adjustment	Drag shaft
Accuracy (%FS)	
Power	1.0
Torque	0.5
Speed	0.5
Torque at zero speed	Yes
Display, Simultaneous/ Selectable	All, simultaneous
Operating Ranges	
Temperature (Sensor)	0°C to 57°C
Temperature (Display)	0°C to 57°C

Table 1,b

Comparison Matrix

Factor	Galbraith-Pilot Marine Corporation
RPM limit	None
Shaft Diameter Limit	None
Installation Clearance	
Radius, inches	6"
Length, inches	40"[i*]
Electrical Power Requirements	115 VAC 60 Hz 300 Watts

*See notes pp. 23-24

Table 1,c

Comparison Matrix

Factor	The Indikon Company, Inc.
Principle of Operation	Strain gage bonded to shaft
Shaft Contact	None, except strain gage and attached portion of rotary transformer
Cost/Shaft	$8000
Current Military Use	None
Installation Time Man-hrs	16[C*]
Calibration	Factory pre-calibrated
Zero Adjustment	None - internal continuous automatic readjustment
Accuracy (%FS)	
Power	1.0
Torque	1.0
Speed	1.0
Torque at zero speed	Yes
Display, Simultaneous/ Selectable	All, simultaneous
Operating Ranges	
Temperature (Sensor)	0°C to 100°C
Temperature (Display)	10°C to 70°C

*See notes pp. 23-24

Table 1,c

Comparison Matrix

Factor	The Indikon Company, Inc.
Rpm Limit Shaft Diameter Limit	None None
Installation Clearance Radius, inches Length, inches	Strain gauge and rotary transformer combined require 4" radial clearance and 6" longitudinal clearance.
Electrical Power Requirements	115 VAC 60 Hz 115 Watts

Table 1,d

Comparison Matrix

Factor	Mechanical Technology, Inc.
Principle of Operation	Change in shaft magnetic characteristics - magnetostrictive
Shaft Contact	None
Cost/Shaft	\$40,000[a, b*]
Current Military Use	NAVY
Installation Time Man-hrs	6
Calibration	On line using secondary torsionmeter or strain gage device
Zero Adjustment	Drag shaft
Accuracy (%FS)	
Power	NA
Torque	1.0
Speed	NA
Torque at zero speed	Yes
Display, Simultaneous/ Selectable	Torque only, NA
Operating Ranges	
Temperature (Sensor)	-1°C to 74°C
Temperature (Display)	-1°C to 74°C

*See notes pp. 23-24

Table 1,d

Comparison Matrix

Factor	Mechanical Technology, Inc.
RPM Limit	None[e*]
Shaft Diameter Limit	None
Installation Clearance	
Radius, inches	4"
Length, inches	8"
Electrical Power Requirements	115 VAC 60 Hz 200 Watts

*See notes pp. 23-24

Table 1,e

Comparison Matrix

Factor	Simmonds-Precision
Principle of Operation	Phase difference in signals generated by magnetic gears
Shaft Contact	Gears mounted on existing coupling or clamp on husk
Cost/Shaft	$8,000 to $12,000
Current Military Use	None
Installation Time Man-hrs	NA
Calibration	Factory pre-calibrated
Zero Adjustment	None
Accuracy (%FS)	
Power	1.0
Torque	0.9
Speed	0.9
Torque at zero speed	No
Display, Simultaneous/ Selectable	All, simultaneous
Operating Ranges	
Temperature (Sensor)	-54°C to 204°C
Temperature (Display)	0°C to 49°C

Table 1,e

Comparison Matrix

Factor	Simmonds-Precision
RPM limit	Above 10% FS[f*]
Shaft Diameter Limit	None
Installation Clearance	
Radius, inches	1"
Length, inches	18"
Electrical Power Requirements	115/230 VAC 50/60 Hz 100 Watts

*See notes pp. 23-24

Table 1,f

Comparison Matrix

Factor	Ultra Products Systems, Inc.
Principle of Operation	Phase difference in signals generated by magnetic tape
Shaft Contact	Nonmetallic tape bonded to shaft
Cost/Shaft	$10,000[a*]
Current Military Use	NTE
Installation Time Man-hrs	4-12[d]
Calibration	On line, no load recording of signals
Zero Adjustment	Drag shaft or no load turning for signal recording
Accuracy (%FS)	
Power	0.5
Torque	0.4
Speed	0.25
Torque at zero speed	No
Display, Simultaneous/ Selectable	All, simultaneous
Operating Ranges	
Temperature (Sensor)	0°C to 50°C
Temperature (Display)	0°C to 50°C

*See notes pp. 23-24

Table 1,f

Comparison Matrix

Factor	Ultra Products Systems, Inc.
RPM limit	Above 10%FS to max of 600 rpm[f, h*]
Shaft Diameter Limit	
Installation Clearance	
Radius, inches	less than 1"
Length, inches	1 1/2 to 2 times diameter[j*]
Electrical Power Requirements	115 VAC 60 Hz 25 Watts

*See notes pp. 23-24

Notes:

a For a recent NAVY purchase of torsionmeters for propeller shafting application, the following bids for 24 units were received:

Ultra Products Systems, Inc.	- $260,200.
Acurex Corporation	- $693,987.
Mechanical Technology, Inc.	-$1099,850.

The prices above from reference 4 reflect the cost of first article testing for both the Ultra Products Systems and Acurex Corporation devices.

b The cost of $40,000 per shaft is based on military version currently in use by the NAVY.

c Rough estimate by manufacturer, no shipboard installation experience, prefers to handle installation at factory on existing or replacement shaft coupling.

d Upper limit on installation time will be approached for retrofit installation. Well cleaned and carefully prepared shafting surface is essential for lasting adhesion of tape.

e An upper limit in shaft speed is imposed by constraining the number of sensing poles (a function of shaft diameter) and the excitation frequency. For fixed diameter (number of poles) the upper limit to shaft speed may be raised by an increase in the excitation frequency.

f Method for sensing shaft speed or torque is inaccurate below 10% of full scale speed.

g Upper limit on full scale speed imposed by telemetry, sufficiently high to be immaterial for most Naval propulsion plant applications.

h Upper limit on full scale speed imposed by maximum permissible tape speed past sensing head, sufficiently high to be immaterial for most Naval propulsion plant applications.

i For 25 inch diameter shaft, measurement is typically over 40 inches. Length varies with diameter.

j Twist may be measured over a distance as small as 1 1/2 to 2 times shaft diameter. The only rotating devices are the bonded magnetic tapes and may be installed on each side of a bearing housing.

List of Manufacturers

Acurex Corporation, 485 Clyde Ave., Mountain View, CA 94042

Galbraith-Pilot Marine Corporation, 166 National Rd.,
Edison, NJ 08817

The Indikon Company, Inc., 76 Coolidge Hill Rd.,
Watertown, MA 02172

Jungner Instrument AB, Marine Division, Svetsarvägen 15,
Fack, S-171 20 SOLNA 1, Stockholm, Sweden

McNab, Inc., 20 North MacQuesten Pkwy., Mount Vernon, NY 10550

Mechanical Technology, Inc., 968 Albany Shaker Rd.,
Latham, NY 12110

Simmonds Precision, Instrument Systems Division, Panton Rd.,
Vergennes, VT 05491

Ultra Products Systems, Inc., 5015 River Rd.,
New Orleans, LA 70123

ANNEX C-II

STATE-OF-THE-ART STUDY

DIVER AND REMOTE VEHICLE UNDERWATER INSPECTION

STATE-OF-THE-ART STUDY

DIVER AND REMOTE VEHICLE UNDERWATER INSPECTION

SPONSORED BY:

Naval Sea Systems Command (SEA 0353)

Washington, D. C.

June 1976

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SUMMARY

The primary purpose of the report is to determine the state-of-the-art for underwater inspection methods and equipment through contact with cognizant organizations in the United States and foreign countries.

Information was obtained through questionnaires and telephone conversations and through a visit to the Charleston Naval Shipyard.

Detailed data is presented for photographic, television, nondestructive testing and remote inspection systems.

Conclusions and recommendations are made concerning the inspection equipment, operational and maintenance personnel and system evaluation methods.

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SECTION 1

INTRODUCTION

The primary purpose of this report is to determine the current state-of-the-art for underwater inspection methods and equipment through contact with cognizant organizations in the United States and foreign countries. Both manufacturers and performing activities have been contacted.

Underwater inspection is one of the major subdivisions of a proposed underwater ship husbandry program. The overall program would also include underwater hull cleaning, painting, repair, and maintenance. The objectives of the ship husbandry program are to increase dry dock interval to seven years and to reduce fuel consumption by at least 10%. The basis for such requirements is the increasing shortage of dry dock facilities and fuel, and the increasing need to keep the ships of our reduced fleet in a high state of readiness.

This report is intended to serve the purpose of making known the equipment and methods available and listing the sources of supply, prices, and inspection rates where possible. An additional basic purpose is to recommend the developments and evaluations that appear essential for Navy ship and submarine underwater inspection in conjunction with the overall ship husbandry program.

SECTION 2

METHODS

2.1 GENERAL APPROACH

The basic approach has been to gain as much information as possible through correspondence and telephone conversations with manufacturers of equipment used for underwater inspection and performing activities. Special questionnaires were used. A visit was made to the Charleston Naval Shipyard to discuss dry dock and underwater inspection, Coast Guard officers were interviewed, and pertinent documents and reports were studied, Section 5, reference. The coauthor, Professor Wyman has served as a Coast Guard Inspector of ships in dry dock and his knowledge of related procedures has been utilized.

2.2 ORGANIZATIONS CONTACTED

Questionnaires were mailed or telephone conversations were held with approximately seventy different organizations. The names and addresses of responding organizations are listed in Section 3.3. It is expected that the replies of many of the overseas activities contacted will be delayed. The full list of activities contacted will be furnished upon request.

2.3 COORDINATION WITH NAVAL SHIP ENGINEERING CENTER AND CONTRACTOR PERSONNEL

The Naval Ship Engineering Center has awarded contracts for preliminary studies in the underwater inspection and hull cleaning areas. A coordination meeting was held at the Naval Coastal Systems Laboratory, Panama City, Florida, in June 1976. The purpose of the meeting was to exchange information in order to avoid duplication and to facilitate program progress. The following personnel participated:

Sherman Cauldwell, Code 6136 NAVSEC, Sponsor Representative
Keith Hallam, Tracor Sciences & Systems
Tom Sullivan, Vitro Laboratories, Div. of Automation Industries, Inc.
K. H. Wellman, West Oceanics Div. of Westinghouse Corp.
J. Quirk, F. Barrett, J. Mittleman, and Robert Elliott, Naval Coastal Systems Laboratory.

As planned, both the Naval Ship Engineering Center studies being performed by the above contractors and the study herein reported, sponsored by the Naval Sea Systems Command, will be utilized in formulation of a master plan for underwater ship husbandry research and development.

SECTION 3

RESULTS

3.1 CHARLESTON NAVAL SHIPYARD DISCUSSIONS

A trip was made to Charleston Naval Shipyard to gather background information as related to underwater hull inspection and cleaning. The visit was coordinated by Mr. Bill Stamey, Diving Supervisor at the shipyard. The visit consisted of discussion with shipyard divers, planning and estimating personnel at both surface and submarine type desks, and cleaning, painting, and nondestructive testing supervisors.

A variety of hull and appurtenance cleaning, maintenance and repair tasks, and inspection tasks are performed. The Underwater Damage Assessment Television System (UDATS) is used extensively and effectively by the diving group for underwater inspection. The use of the TV monitor located topside permits technical personnel and supervisors to view the underwater structures and the progress of the repair work. Permanent records may be made using the video tape recording subsystem.

The four major types of testing performed by the Nondestructive Testing Department are radiographic, ultrasonic, magnetic particle, and dye penetrant. Both ultrasonic and radiographic testing may be done underwater.

The trip report constitutes Appendix A.

3.2 DRY DOCK INSPECTION REQUIREMENTS AND PROCEDURES

Much of the inspection work currently performed in dry dock will have to be performed underwater to meet the goals of the overall ship husbandry program. The following information is, therefore, considered to be of basic importance in understanding underwater inspection requirements.

All ships require periodic inspection of their external submerged areas to determine their structural adequacy and to plan any needed repairs. To accomplish the inspection of the underwater hull areas, ships have traditionally been drydocked (i.e., removed from the water so the necessary inspection and repairs could be accomplished in an air environment). The drydocking of vessels, particularly large vessels, is costly—the out-of-pocket cost for physically placing the vessel in drydock must be paid, the cost of the vessel being out of service during the drydocked period and other costs associated with moving the ship to the drydock such as fuel to steam to the drydocking port, and extra expenses incurred in providing hotel services for the crew. Conversely, an underwater hull inspection could be performed with minimal interference to the normal ship routine (i.e., whenever or wherever the vessel is moored in calm water provided the necessary equipment and trained personnel are available). She could also be easily activated by suspending the inspection and have her get underway. This would be difficult to do if she were in drydock.

U.S. Naval Ships.

The United States Navy requires that most of its seagoing ships be given a drydock inspection every three years[1]. Certain types of ships such as wooden-hulled minesweepers must be drydocked more often[2]. The drydock inspection consists of a complete visual inspection of the underwater body of the vessel and detailed physical inspections of such items as bearing clearance, condition of sea valves, propellers, rudders, etc.

The drydock inspection starts with a propeller vibration survey conducted prior to docking the vessel. The results of this test will determine the advisability of removing the propeller and withdrawing the tail shaft for a detailed inspection of each. If the tail shaft is not pulled (about one out of seven drydocked ships need the shaft pulled),[3] the shaft bearing clearances are taken by removing the fair waters and rope guards and then using a feeler gauge. The clearance on rudder bearings and any other external bearings are also measured. Prior to inspecting the hull, it must be cleaned of marine growth, loose paint, and any other foreign matter. Once cleaned, the drydock inspection team consisting of a ship's representative, a SUPSHIPS representative, and various shipyard representatives conduct a general hull inspection. They will be looking for the condition of the coating system, general condition of the underwater hull plating and evidence of any damage to the underwater hull structure. Welds are checked for corrosion. Specific items such as the cathodic protection system and sea chests will be examined in detail. Areas of high stress such as the stern frame and the rudder are examined for cracks. The thickness of the hull plating may be gauged if considered necessary. Later, sea valves are disassembled and inspected. The propeller is also carefully examined for cracks and other damaged areas.[4] A typical drydock Inspection Report is completed.

Drydock Inspection Requirements and Procedures for U.S. Government Ships Other Than U.S. Navy

Ships are operated by many U.S. Government agencies in addition to the Navy, a few of which are the U.S. Coast Guard, U.S. Army Corps of Engineers, and the National Oceanic and Atmospheric Administration. These agencies all require that their vessels be drydocked at regular intervals for inspection. For example, the Coast Guard requires routine drydocking at two-year intervals with an option for an additional year if the expected life of zincs and coating systems is adequate and the general hull condition from the last drydock inspection or diver inspection is satisfactory.[5] When the vessel is drydocked, the following items are routinely inspected: the coating system; the cathodic protection system; all appendages such as rudders, bilge keels, skegs, etc.; general hull condition with regard to corrosion; plate thickness and mechanical damage. Welds and rivets are also examined, the bearing clearances for propeller shafts and rudder shafts are measured, and sea chests and sea valves are inspected.[6] The Coast Guard Ship's Technical Manual, Chapter 9070, and Coast Guard Drydocking Forms CG 2926 and CG 4815 provide basic instructions. The importance of maintaining records of the underwater hull condition is emphasized particularly as a basis for extending the drydock interval.[3]

These records are also important in assessing the rate of gradual deterioration (i.e., corrosion of the underwater hull structure).

Drydocking Inspection Requirements and Procedures for Merchant Ships

Most merchant ships are required by law and/or their insurance contracts to be drydocked at regular intervals—the usual interval between required drydockings is two years.[7] The inspection of United States merchant vessels is carried out both by the U.S. Coast Guard, which has a legal responsibility to verify the seaworthiness of the vessel, and the American Bureau of Shipping (ABS), which classes ships for insurance purposes. After the vessel has been placed in drydock and cleaned, the inspection party made up of the owner's representative, U.S. Coast Guard Inspector, ABS Surveyor and a shipyard representative inspect the hull for general condition of hull plating and appendages, the condition of propellers and rudders and their bearing clearances, the condition of sea chests and sea valves. The coating system is the concern of the owner but not the regulatory bodies.[8]

The Maritime Administration of the U.S. Government is charged with aiding the development of the U.S. merchant fleet. Drydocking, because of its substantial cost, both in money and ship's time, has recently been studied to determine if there are more cost-effective ways to inspect and maintain the underwater portion of a ship's hull and appendages.

The basic results of the Maritime Administration studies point to the development of underwater inspection and maintenance of merchant vessels.[9]

Specific Items Inspected at Drydock Inspections

U.S. Navy, U.S. Coast Guard, and merchant ship drydock inspection procedures have been reviewed and all appear to require essentially the same items to be inspected and with similar criteria. This is natural because most surface ships' underwater hull areas and appendages are basically the same. The following is a general list of items inspected during a ship's routine drydock inspection:

Routine Drydock Inspection - Items Inspected

General Hull Structure:

- Plating - corrosion, wastage, cracks, leaks, pitting
- Plating thickness gauged
- Welds - deteriorated or cracked
- Docking Plugs
- Indents
- Rivets - loose, deteriorated heads
- Large scale distortions (setup areas)

External Structural Members:

- Stern frame - cracks
- Bilge keels
- Stem frame

Sonar Transducers:

Bow Thruster:
- Bearing clearances
- Propeller
- Guards

Rudders:
- Plating - thickness, cracks
- Welds - deteriorated, cracks
- Bearings - clearance, loose pintles
- Rudder palms - cracks, loose bolts

Propellers:
- Blades - bent, cracks, missing parts, corroded areas
- Locknuts
- Cap, rope guard

Tail Shafts:
- Bearing clearance measured
- Oil Leaking
- Drawn for inspection

Sea Chests:
- Master pieces
- Strainers
- Welds - deteriorated
- Plated - thickness, corrosion, pitting

Sea Valves:
- Disassembled for inspection

Cathodic Protection:
- Zincs
- Impressed current system

Coating System:
- Antifouling system
- Anticorrosive system

Current Practices in Underwater Inspections

A. Underwater Hull Inspections.

For many years the U.S. Navy, like most other ship operators, has used underwater inspections of ships' hulls to assess damage or to verify the condition of specific items, but not to take the place of the required routine drydock inspections. Divers have been employed to determine the condition of the bottom of a ship prior to drydocking if it had suffered a grounding type of accident. The diver would, by feel and by sight, determine the condition of the bottom. This proved to be inadequate in many cases because of the many difficulties the diver encountered (i.e., limited visibility, diver unfamiliar with the ship, difficulty of finding a given location on the ship's bottom, etc.). The advent of underwater television has helped because it allows the topside decision makers to look at the areas of interest. The Navy's Underwater Damage Assessment Television System (UDATS) is one of the systems in regular use, which has made possible a significant step forward in underwater inspections.

At present, there is a push to extend drydocking intervals to longer and longer periods. Ten years ago every seagoing U.S. merchant ship was drydocked for inspection every 18 months; now the requirement is every two years[10] and in the future, it will probably be extended. The push for extended drydocking periods from commercial ship operators is two-fold, both due to the nonavailability of drydocks for the very large ships and also the cost. Recently an underwater ship inspection station was put into operation in the Canary Islands. It appears that this station has already completed underwater hull inspections on a few very large tankers that have been acceptable to foreign classification societies in lieu of a drydock inspection.[11]

It also appears that the U.S.S.R. is presently using underwater inspection and repair techniques for some of their ships as indicated in a translation of a Russian report on "Underwater Ship Repair" by N. M. Madatov.[12]

B. Underwater Inspections of Offshore Structures.

The Offshore Oil Industry has used underwater inspection techniques on its offshore fixed structures because these cannot be removed from the water for inspection of their structural adequacy. Visual inspections are carried out by divers and by television, both diver operated and remotely controlled from the surface. Other types of nondestructive testing have also been used.[13]

This is an area where it appears that a great deal of work has been done and needs further investigation by this group because much of it may be applicable to underwater inspection of ships.

3.3 STATE-OF-THE-ART SURVEY

3.3.1 Questionnaire Response Summary

Approximately 63 organizations involved in underwater inspection or the manufacturer of underwater inspection equipment were contacted by phone or letter.

Underwater inspection performer type questionnaires have been returned by the following:

Coastal Diving Company
P.O. Box 1552
Vallejo, Calif. 94590

Comex Diving Limited
Unit 8, Bessemer Way, Harfreys
Ind. Estate, Great Yarmouth,
Norfolk, Va.

Harter Underwater Corporation
2824 Solomons Island Road
Edgewater, Md. 21037

H. M. Tiedman and Company, Inc.
25 Greenwich Avenue
Greenwich, Conn. 06830

Isle-Dive
P.O. Box 17417
Honolulu, Hawaii

Oceaneering International
6269 Leesburg Pike
Falls Church, Va. 22044

Ocean Systems, Inc.
11440 Isaac Newton
Industrial Square N.
Reston, Va. 22090

Peabody Testing Services
7300 W. Lawrence Avenue
Chicago, Ill. 60656

Perry Oceanographics, Inc.
Perry Building
100 E. 17th Street
Riviera Beach, Fla. 33404

Subservices, Inc.
P.O. Box 5034, Cristobal
Canal Zone

Tidewater Diving Services
2407 W. Rogers Avenue
Baltimore, Md. 21209

It is expected that many more replies will be received as a considerable number of the questionnaires were mailed to organizations located in other countries.

The replies are listed in Table 3.1.

3.3.2 Underwater Television Systems

All of the underwater television systems for which information has been received are listed in Tables 3.2 and 3.3

It is beyond the scope of this report to evaluate the relative effectiveness of such systems.

The UDATS is the only system known to be built to Navy military specifications. The UDATS is used very effectively by Navy enlisted and shipyard diving groups.

3.3.3 Underwater Photographic Systems

All information received concerning underwater photographic equipment has been listed in Tables 3.4 and 3.5. It is beyond the scope of this report to evaluate the relative suitability of such equipment. The evaluation requirements are discussed in the Conclusions and Recommendations sections of this report.

3.3.4 Non-Destructive Testing Systems

It was particularly difficult to obtain information in this area. It has been determined, however, that nondestructing testing is used extensively in inspection of offshore petroleum platforms. It is also used in inspection of ship hulls and other structures, particularly by foreign inspection teams.

All nondestructive testing equipment for which information was received is contained in Table 3.6.

3.3.5 Remote Inspection Systems

The remote systems are listed in Tables 3.7 and 3.8. SCAN appears to be the only system designed specifically for use in ship hull inspection. Unfortunately, the system is not available commercially and it has not been possible to directly contact the developers to date. The other listed systems appear to be better suited for such tasks as underwater cable, pipeline and offshore structure inspection.

TABLE 3.1

QUESTIONNAIRE RESPONSES
FROM
INSPECTION PERFORMING ORGANIZATIONS

1. Type of structures or vessels inspected.

HARTER UNDERWATER CORPORATION. Commercial ships, bridge piers, dam intakes, pier supports, pipelines, sunken ships.

H. M. TIEDMAN AND COMPANY. Ships, barges, offshore structures including fixed structures, semi-submersibles and jack-ups.

ISLE DIVE. Civilian merchant and U.S. Navy vessels (support and ships of the line).

OCEANEERING INTERNATIONAL. Typically, aircraft, satellites or pieces of ordnance which have sunk at sea and occasionally sunken ore carriers.

OCEAN SYSTEMS, INC. Pipelines, ships, barges, structures and piers.

PERRY OCEANOGRAPHICS, INC. Offshore petroleum structures.

SUBSERVICES, INC. Over 150 vessels have been inspected (1973-1976) at ports in Cristobal, Balboa, Las Minas, Tobago, and Colón.

COASTAL DIVING COMPANY. Dam trash racks, vessels, piers and piling, gate valves, pipelines, cables and fire-water tanks.

PEABODY TESTING SERVICES. Ship hulls, storage vessels and offshore platforms.

TIDEWATER DIVING SERVICE. We have inspected every type of craft from experimental submarines through very large crude oil tankers.

COMEX DIVING LIMITED. Oil rigs, offshore platforms and anything that floats.

2. Usual location of inspection site.

HARTER UNDERWATER CORPORATION. In harbors or rivers.

H. M. TIEDMAN AND COMPANY. On offshore structures, the inspection would be done at the site; on ships it would be done in harbors at any location.

ISLE DIVE. Usually the ships are located in Honolulu Harbor, Pearl Harbor Naval Base or anchored off-shore.

OCEANEERING INTERNATIONAL. At sea.

OCEAN SYSTEMS, INC. Any water location: bays, lakes, harbors, and at sea.

PERRY OCEANOGRAPHICS, INC. Gulf of Mexico.

SUBSERVICES, INC. Harbors of Cristobal and Balboa.

COASTAL DIVING COMPANY. May be taken anywhere.

PEABODY TESTING SERVICES. Both in harbors and at sea.

TIDEWATER DIVING SERVICES. Shipyards to off-shore.

COMEX DIVING LIMITED. At sea.

3. Maximum and usual depths at which inspection was accomplished.

HARTER UNDERWATER CORPORATION. 190' - 5' to 100'.

H. M. TIEDMAN AND COMPANY. 200' for SCUBA - 60' to 110'.

ISLE DIVE. No limit - bottom of ship.

OCEANEERING INTERNATIONAL. Remote at 4,100' - 50' to 200'.

OCEAN SYSTEMS, INC. 1500' for diver and TV - varies.

PERRY OCEANOGRAPHICS, INC. Recon II - 1500'; Recon IV - 3000' Usual 0-250'.

SUBSERVICES, INC. 250' - 40'

COASTAL DIVING COMPANY - 200' 0-70 usual.

PEABODY TESTING SERVICES. 600'. Usual up to 200'.

TIDEWATER DIVING SERVICES. 150' max.

COMEX DIVING LIMITED. 1000'. 160' usual.

4. Primary purpose of inspection.

HARTER UNDERWATER CORPORATION. Damage assessment or compliance with instruction specifications.

H. M. TIEDMAN AND COMPANY. Our SCUBA, video inspection techniques which use ultrasonic testing devices were inaugurated about 12 years ago when we did the offshore structure Argus Island Tower, off the coast of Bermuda. This technique has been developed for ships and other floating structures. As a new development, we are proposing the seismic vibration analysis technique which we have pioneered over the last five years. This technique allows us to check the structure in a very short time to determine whether or not we have a failure in either a primary or secondary strength member.

ISLE DIVE. To ascertain condition of hull with an eye towards cleaning or repairs.

OCEANEERING INTERNATIONAL. Usually accident or salvage inspection purposes.

OCEAN SYSTEMS, INC. They were varied but usually assessment of wear, corrosion, damage and need for maintenance.

PERRY OCEANOGRAPHICS, INC. To determine the condition of various component parts of offshore structures.

SUBSERVICES, INC. To locate and repair damage, determine the extent of fouling and the condition of bottom structures, pipes and piling.

COASTAL DIVING COMPANY. Engineering, work progress/completion and locating problem areas.

PEABODY TESTING SERVICES. Determine existing material thickness and weld quality.

TIDEWATER DIVING SERVICES. To determine whether or not hull cleaning is required and to assess propeller shaft, rudder, zincs, sea chests and other damage that may have occurred.

COMEX DIVING LIMITED. To locate faults in structures.

5. Who makes the decisions as to what repairs or actions are required as a result of inspection.

HARTER UNDERWATER CORPORATION. Ship repair facility consulting engineers, general contractors, etc.

H. M. TIEDMAN AND COMPANY. The owners, American Bureau of Shipping or U.S. Coast Guard Inspectors and recommendations of our company.

ISLE DIVE. Ship owner or representative or master ship repairer.

OCEANEERING INTERNATIONAL. As these are salvage operations, the customer makes the decisions.

OCEAN SYSTEMS, INC. The owner of the inspected structure.

PERRY OCEANOGRAPHICS, INC. All decisions are made by the contractor.

SUBSERVICES, INC. Our marine superintendent, along with classification surveyors if they are involved. Salvage Association Surveyors are also consulted.

COASTAL DIVING COMPANY. Customers.

PEABODY TESTING SERVICES. Quality control and structural engineers and owners representatives.

TIDEWATER DIVING SERVICE. The owner of the vessel through his appointed representative who may be an operations officer or a part captain.

COMEX DIVING SERVICES. The client.

6. What data must be furnished as the basis for such decisions?

HARTER UNDERWATER CORPORATION. Locations, dimensions, bottom conditions, current, general conditions, openings in hulls, pipe fittings, etc.

H. M. TIEDMAN AND COMPANY. Data output from our SCUBA video-ultrasonic team or with the new pickup device technique, the data from our transducer pickups. Utilizing the new technique, we would need the structural details of the structure being analyzed.

ISLE DIVE. Verbal observations, written reports, 35 mm still photographs, and UDATS video.

OCEANEERING INTERNATIONAL. We usually furnish recommendations as to the feasibility of salvage and cost estimates.

PERRY OCEANOGRAPHIC, INC. Video tape recordings.

SUBSERVICES, INC.

1. Nature and extent of damage.
2. Manner we propose to effect repair, along with estimates for time and cost.

PEABODY TESTING SERVICES. Original material thickness, weld configuration and location of structural members.

TIDEWATER DIVING SERVICES. Verbal report, video tapes and photographs.

COMEX DIVING LIMITED. Full written report of findings plus sketches of damaged areas.

7. Please furnish as much technical information as possible concerning the inspection equipment used.

HARTER UNDERWATER CORPORATION. It varies, but diver sense of touch for the most part due to lack of visibility.

H. M. TIEDMAN AND COMPANY. Hydro Products TV and Krautkramer ultrasonics testers and recorders and our proprietary vibration equipment.

OCEANEERING INTERNATIONAL. Hydro products TV, Varian or Geometrics, magnetometers and Klein or EGG side scan sonar.

OCEAN SYSTEMS, INC. Esso Products Research ultrasonic gear and Sub-Sea and Aquadyne TV equipment.

PEABODY TESTING SERVICES. We use a Magnuflux Corporation Model PS-702 portable pulse ultrasound test instrument.

TIDEWATER DIVING SERVICES. Our equipment ranges from underwater TV through ultrasonic submarine electronic calipers.

COMEX DIVING LIMITED. Closed circuit television. Comex developed portable magnetic particle inspection for use in depths to 300', ultrasonic inspection "D " meter, Hydroscan camera and Calyposo-Nikkor photo system and radiographic inspection equipment.

8. Man-days required to inspect different types of structures or ship hulls.

PEABODY TESTING SERVICES.
Tanker (empty) 4 belts - 60 man hours
Tanker (full) 4 belts - 150 man hours
Using two men-empty and two divers full.

TIDEWATER DIVING SERVICES. The only work that takes in excess of 16 hours of diver time to perform is ultrasonic testing which may take up to 40 diver hours for a very large vessel.

H. M. TIDEMAN AND COMPANY. About 3 days using SCUBA for large ships.

ISLE DIVE. Two man days for the usual ship. A 1000 super tanker can be inspected with UDATS in eight man hours.

9. Please describe any special equipment or methods for working in turbid water.

COASTAL DIVING COMPANY. For dark water we use one or two standard movie lights (110 v) attached to the camera. Quartz lights with red or green spectrum are used. We also use a clear water box or bag, lens to object.

TIDEWATER DIVING SERVICE. We have special equipment but it is proprietary.

H. M. TIDEMAN AND COMPANY. On the vibration signature technique (proprietary) it makes no difference if the water is turbid.

OCEAN SYSTEMS, INC. We use clouds of clear or fresh water.

TABLE 3.2. UNDERWATER TELEVISION SYSTEMS

NOMENCLATURE	MODEL	MANUFACTURER	ADDRESS	CAMERA TYPE	SENSITIVITY	LENS	DEPTH LIMIT	CABLE	REQ. POWER	DIVER COMMUNICATION
Rebikoff-Alpha "Videomarine"	DR 1	Rebikoff Institute of Marine Technology	360 S.W. 4th Ave., Ft. Lauderdale FL 33315	Vidicon	400	10 mm F1:1.8	300m/ 1000'	100m/ 330'	115 V 50/30 cycle or 12 VDC w/inventer	
Rebikoff-Alpha "Videorama"	DR 4	"	"	Low light level	600	105^{o} wide angle 5.9 mm F1.8	300m/ 1000'	Optional at $2.49 per ft.	115V 60 Hz	
Rebikoff-Alpa "Videorama"	DR 60	"	"	Stabilized low light level ruggedized	600	Zoom	660'	100m/ 330'	115 V or 230 V 60 Hz	
Surveyor	TC 125 camera mineraturе	Hydro Products	P.O. Box 2528, San Diego, CA 92112		525	63^{o} 6.5 mm F1.2	300m/ 1000'	100m/ 330'	Camera 15 VDC light- 28 VDC 115 VAC 60 Hz to control unit	Diver surface
UDATS (Underwater Damage Assessment TV System)	TC125-D1 Camera	"	"	Vidicon	600 lines at 0.1 foot candles	46" 12.5 mm F1.4	300'		12 VDC at camera 115 VAC 60 Hz to light and control unit	
Low Light Level TV Camera	TC-125-SIT	Hydro Products	P.O. Box 2528, San Diego, CA 92112	Low light level	High level resolution at 0.0005 foot candles and 400 lines	39^{o} 12.5 mm F1.4	2000'		12 VDC	
TV Camera	CM-7	Sub-sea Systems, Inc.	753 Washington Ave., Escondido CA 92025	Hybrid Vidicon	600 TV lines at 300 NA S.C. with up to 1000' of cable	48.4^{o} 12.5 mm F1.9	2000'		Camera 8 VDC 60 Hz optional	

TABLE 3.2. UNDERWATER TELEVISION SYSTEMS (Continued)

NOMENCLATURE	MODEL	MANUFACTURER	ADDRESS	CAMERA TYPE	SENSITIVITY	LENS	DEPTH LIMIT	CABLE	REQ. POWER	DIVER COMMUNICATION
TV System		Sub-Sea Systems, Inc.	753 Washington Ave., Escondido, CA 92045				2000'	300'	120/ 240 VAC 60 Hz	
TV Camera	104	Bush Oceanographic Equip. Co.	214 S. Hamilton St., Saginaw, MI 48602	Vidicon or tow light level	500 lines at one foot candle 0.0005 for low light level	58^{o} hor. 8.5 mm F1.9	3000'	300'	120 VAC 60 Hz (36 VDC available)	
TV System		"	"				3000'		120 VAC 60 Hz	
TV Camera	1441	Edo Western Corp.	2645 South 300 West Salt Lake City, Utah 84115	Vidicon	Face plate illumination 0.05 foot candles 800 line resolution		5000'	2000'	110 VAC 60 Hz or 200 VAC 50 Hz	
Diver Held U/W		Edo Western Corp.	"					300'	"	
Observer II Television System	II	Aquadyne	333 E. Haley St., Santa Barbara, CA 93101	Vidicon low light level	525 lines	Wide angle 8.5 mm F1.5	400'	2000' max	Self contained battery or 12 VDC or 115 VAC	Two-way diver surface
Sea Snoop		Seacor, Inc.	P.O. Box 22126 San Diego, CA 92122		300 lines		600'		Self contained or 117 VAC 60 Hz	

TABLE 3.3. UNDERWATER TELEVISION SYSTEMS (ADDITIONAL DATA)

NOMENCLATURE	MODEL	TYPE FOCUS	B&W OR COLOR	LIGHT	LIGHT CONTROL	MONITOR SIZE	SYSTEM COMPONENTS	CAMERA SIZE	CAMERA WEIGHT	COST
Rebicoff-Alpa "Videomarine"	DR 1	Lens contact-infinity	B&W	250W		9"	TV, monitor cable & light	6" dia x 23"	28 1/2 lbs	$ 4,650
Rebicoff-Alpa "Videorama"	DR 4	Automatic lens contact-infinity	B&W, color optional	250W		9"	TV, monitor 300' TV cable 300' light cable marine shipping cases	6" dia x 23"	28 lbs	13,385
Rebicoff-Alpa	DR 60	Fully automatic	"	250W		9"	TV, monitor 330' cable safety transformer, light case			
Surveyor		Remote 3" infinity	B&W	75W tungsten halogen	Automatic		TV, monitor 330' cable light video recorder case, control unit cases	9" LX 5" WX 2 1/8" T	less than 1 lb in water	
UDATS		Automatic 3"-infinity	B&W	240 W, Thallium Iodide			TC-125 DJ camera, LT-8 light, KMB-9 mask, SC-303-HW control unit (contains monitor & speaker), AV-3650 Video Recorder, Frequency Stabilizer shipping cases, test cable	3" dia. x 21"	12 lbs 8 lbs in water	18,250
Low light level TV camera	TC-125-SIT	10" infinity motor controlled	B&W				TV camera only	4" dia. x 20"	26.3 lbs 17.1 lbs in water	16,990
Fluid port for TC-125 camera (Provides 12" dia. window of clear water)	Hydro Products									
TV Camera	CM-7	Remote control	B&W					2.25" dia. x 17.75	12.75 lbs 21 lbs in water	4,200
TV System	Sub-sea		B&W	400 W mercury vapor		9"	CM-7 camera, MK-XA light C-5 BU cable, MK-IXP lamp power supply, MC S-3 monitor, tape recorder			9,755

TABLE 3.3. UNDERWATER TELEVISION SYSTEMS (ADDITIONAL DATA) (Continued)

NOMENCLATURE	MODEL	TYPE FOCUS	B&W OR COLOR	LIGHT	LIGHT CONTROL	MONITOR SIZE	SYSTEM COMPONENTS	CAMERA SIZE	CAMERA WEIGHT	COST
TV Camera	104	Fixed 4" - Inf.	B&W			10"		3.25 dia x 17.75	11 lbs	$ 2,400 or 3,237 for low light level
TV System	Busch	Fixed 4" - 20'					104 camera, 104C control console and power supply for lights (includes 10" monitor), 104L5 light 104 VTR tape recorder.			7,340 or 9,137 for low light level
TV Camera	1441		B&W					3.25 dia x 15"	9 lbs 7.6 lbs in water	3,652
Diver Held U/W TV System	Edo Western			Thallium Iodide			1441 camera, 1205 light 9114 monitored control unit, 581 float			9,492
Observer II TV System	II	Fixed 3" to infinity	B&W	28 V bulb		8"	8929 camera and type 965 lamp mounted on helmet model DM-5, video monitor tape recorder, voice communications, batteries			17,000
Sea Snoop		6" to infinity	B&W				Self contained camera system with instant diver replay			15,000

TABLE 3.4. UNDERWATER PHOTOGRAPHIC EQUIPMENT

CAMERAS

NOMENCLATURE	MODEL	MANUFACTURER	LENS	NO. EXPOSURES	DEPTH LIMIT	FILM TRANSPORT	FILM SIZE	SPECIAL FEATURES	COST
Nikonos All Weather Camera	*III*	*Ehrenreich* Photo-Optical 623 Stewart Ave. Garden City, N.Y. 11530	35 mm F2.5	36	160'	Manual	35 mm	Corrosion resistant Rapid lever advance Large shutter speed control Frame finder for 35 mm & 80 mm lenses Film travel rewind indicator	$300 approximate
Edgerton Deep Sea Utility Camera	371	Benthos, Inc. North Falmouth, Mass. 02556		20 80 using thin base film		Remote Elect.	35 mm	Electric connection to flash unit and external trigger. Optional connection for external power source. Shutter speed controllable manually or remotely. External lens aperture and focus control.	$3250
Edgerton Deep Sea Standard Camera	372	Benthos, Inc. North Falmouth, Mass. 02556		800	12,000m	Remote Control	Kodak No.10	Run number and time available on each frame. May be used with high intensity flash. Two cameras may be used for stereo.	$4850. 990 extra for data option

UNDERWATER PHOTOGRAPHIC EQUIPMENT (additional data)

NOMENCLATURE	MODEL	POWER	TIMING	WEIGHT	SIZE
Edgerton Deep Sea Utility Camera	371	3-9 volt Mallory MN-1604 batteries	None	33 lbs 26 lbs in water	4.9" dia. x 14.4
Edgerton Deep Sea Standard Camera	372	28 VDC	Date and time to one second (option)	46 lbs 35 lbs in water	4.9" x 24.4".

TABLE 3.5. PHOTOGRAPHIC ACCESSORIES

UNDERWATER LIGHTS

NOMENCLATURE	MODEL	MANUFACTURER	DEPTH LIMIT	MATERIAL	SIZE	POWER	COLOR TEMP	SPECIAL FEATURES	COST
Oceanic Strobe	2001 2002 2003	Oceanics Products 814 Castro Street San Leandro, CA 94577	300'	High impact cycolac	5" dia x 8½"	GE NiCad Batteries	5800°	Mount to ball joint arms Corrected dome port provides 95° 95° angle of coverage. Four hours total charging time. 2001 - 360 flashes Manual ON-OFF switch. 2002 - Allows for automatic operation in conjunction with the Ocean Hydro Eye housing and Honeywell Strobe-Eye. 2003 - Dual power electronic flash. Up to 430 flashes on low power setting. Three position, high-low-off switch.	$389 for 2001 $495 for 2003
Oceanic Strobe	2000	Oceanics Products			2 7/8" dia x 6"	2-C Alkaline Batteries		250 flashes per set of batteries Ready light port ON-OFF switch and E-O connecting cord.	199
Deep Sea Utility Flash	381	Benthos, Inc. North Falmouth, MA 02556			7.5 dia x 17.1"	510 V Gould-Burgess U320 or Mal-lory PF 497 batteries.		Will provide 500 flashes before battery discharge 1 ms flash duration 23 lb. in water weight.	2200
Deep Sea Incandescent Light	398	Benthos, Inc.	Unlimited	Glass and stainless steel				Quartz-iodide lamp 250, 500 or 750 watts	
Snooper Light	5535	Birns & Sawyer 6424 Santa Monica Blvd., Los Angeles, CA 90038 (213) 404-5166	2500'			24 re-charge-able nickel cadmium batteries	3400° Kelvin	Average battery life is 25 min at full power and 60 min at half power 250 watts 22,032 center beam candlepower	$970
Snooper Light	5565	Birns & Sawyer	11,000'			120 VAC 60 Hz 1000 watts	3400° Kelvin	75 hours average lamp life Remote powered	$495

TABLE 3.5. PHOTOGRAPHIC ACCESSORIES (Continued)

NOMENCLATURE	MODEL	MANUFACTURER	DEPTH LIMIT	MATERIAL	SIZE	POWER	COLOR TEMP	SPECIAL FEATURES	COST
Sea Star Strobe	III	Underwater Enterprises, 485 Fourth St., San Francisco CA 94107	300'	Cast aluminum	4½" dia x 9½"	50 w.s. half power 100 w.s. full power uses 2V6-9 volt battery and 510 v. photoflash battery		Open water sync. terminals Multiple power settings Pulsing ready light 360° slave coverage 4 sec full recycle time 600-750 flashes 3 position switch Mates with Nikonos	$263 with bracket and cord
Underwater Light	L7	Hydro Products P.O. Box 2528 San Diego, CA (714) 453-2345	15,000'	Anodized aluminum or stainless steel	5'9" wide x 10" long	115 VAC 60 Hz		May be used with 500 watt quartz iodide, 250 watt mercury vapor or 350 watt thallium iodide light elements. Uniform flood, approx. 90° square with no hot spots. 2000-4000 min. centerbeam candle-power. 3 lbs in water.	$625
Underwater Mercury Light	L2	Hydro Products	8000'	Stainless Steel	3.25" dia x 12"	110 VAC 60 Hz 10 amps 1000 watts		54,000 lumens. Spectral response ideal for U/W TV cameras	$800
Underwater Light	HQ	Hydro Products	1000'	Aluminum Stainless steel optional		115 VAC 60 Hz	3000°K	500 hour bulb life Usable in air or water 1.5 lbs 1.0 lbs in water 10,000 lumens max. Uniform 100° x 100° flood Uses quartz iodide lamps	$390

UNDERWATER HOUSINGS

NOMENCLATURE	MODEL	MANUFACTURER	LENS	DEPTH LIMIT	MATERIAL	SPECIAL FEATURES	COST
Hydro 35	35	Oceanics Products 814 Castro St. San Leandro, CA 94577	Optically corrected		Cast Aluminum	Will accommodate either the Nikon F., Nikon Motor Drive, Nikon F2, Nikon F2 Motor Drive or Canon F1 cameras. Flat port and fish eye port options. Full frame through lens viewing. "O" ring seals Remote control option.	$595 $ 50 motor drive
Leica Underwater Camera Housing	KG-24A NSN-6720-00-111-5819		90°	450'	Aluminum	Will accept any Leica M. Series camera except M-5. Has Leitz Elcan C240 water contact lens. External control of focus shutter speed, aperture setting shutter release and film advance sighting device. Provides for camera sync of flash bulbs or electronic flash.	$829

TABLE 3.5. PHOTOGRAPHIC ACCESSORIES (Continued)

UNDERWATER CAMERA LENS

NOMENCLATURE	MODEL	MANUFACTURER	DIA	FOCAL LENGTH	F. NO.	FOR USE WITH	SPECIAL FEATURES	COST
Micro Lens III			51 mm	183 mm		Nikonos or Calypso Cameras	4" to 8" camera to object distance 1" depth of field at f2.5. 4" depth of field at f22. May be removed or replaced underwater.	$50

TABLE 3.6. UNDERWATER NON-DESTRUCTIVE TESTING EQUIPMENT

NOMENCLATURE	MODEL	MANUFACTURER	ADDRESS	PURPOSE	CAPACITY	ACCURACY	SIZE	WEIGHT	COST
D-Meter w/underwater housing and transducer	D-meter DMUH-1 KMR4-W respectively	Krautkramer-Branson	Jackson & Assoc. 1200 N. Buford Hwy Norcross, GA	Steel or aluminum thickness gauge	.047-2.4"	±.004"	6" x 5" x 3"	4 lbs	$3160
Eddy Current Crack Detector	UWH-1 includes accessories	Hocking Assoc.	Detek Inc. 6805 Coolridge Camp Springs, MD	Surface crack detection in metals	Adjustable		9" Dia	17 lbs	$2575
Portable Pulse Ultrasound Test Instrument	PS-702 AT-1000 module may be added for automatic or semiautomatic operation.	Magnaflux Corp.	7300 W. Lawrence Ave. Chicago, IL 60656	Thickness measurement	1/4" to 25'		15" x 7" x 5"	11½ lbs	$3200
Underwater Ultrasonic Thickness Gauge	NDT-110U	Nortec Corp.	3001 George Washington Way Richland, VA	Metal and plastic thickness gauge	.10-2.0"	±.001"	9" x 6" x 7"	9.5 lbs	$1795
Portable Ultrasonic Thickness Gauge	NDT-120*	Nortec Corp.		Metal and plastics thickness gauge	0.5 to 5"	±1% of full scale. ±.002 in the 1" range.	6½ x 7 3/4" x 9"	7 lbs	$1495
Ultrascope	NDT-131*	Nortec Corp.		Flaw detection and thickness gauge Corrosion detection weld inspection	.10 to 250"	±1% of full scale	4½" x 9½" x 11"	12 lbs	$2995
Digital Ultrascope	NDT-131D	Nortec Corp.		Same + detection of laminations voids and cracks	.02 to 250"	±.0001" on most sensitive scale.	6" x 9½" x 11"	16 lbs	$4795

*Non-waterproof but may be used with long transducer cable (up to 250').

TABLE 3.7. REMOTE INSPECTION SYSTEMS

NOMENCLATURE	MODEL	MANUFACTURER	PURPOSE	INSTRUMENTS	DEPTH LIMIT	PROPULSION	SPEED	COST
Dows	2000	Ametec/Straza 790 Greenfield Drive El Cajon, CA	Offshore, oil inspection, survey and maintenance Site survey Mooring inspection Pipeline and pipeline route survey.	TV, photo cameras and acoustic sensors Doppler sonar navigation. Compass, Depthometer, Altimeter	2000'	3-5 hp motor and nozzle assemblies	3.5 kn	
Sea Surveyor	DR-32	Rebikoff Inst. of Marine Technology 3060 S.W. 4th Ave. Ft. Lauderdale, FL 33315	Ship hull, pipeline offshore oil installation and platform inspections.	TV, photographic camera. Navigation system and instruments	660'		5 kn	
Remote Control Vehicle		Busch Oceanographic Equipment Company	Designed to replace submersible or diver inspection tasks	TV, photographic still and motion picture cameras Sonar transducers *Tracking sonar* optional.	600'	4 - 1 hp motors	2 kn	$50,000
RECON	II	Perry Ocean Group P.O. Box 10297 Riviera Beach, FL 33404	Television and work vehicle. Platform, pipeline salvage, and oceanographic survey.	TV, compass, depth gauge and current/ speed meter	3000'	4 thrusters 5 h.p. total		
SCAN		Underwater Maintenance Company Limited. Las Palmas, Canary Islands	Ship hull inspection	TV and photographic cameras			50 meters per min.	

TABLE 3.8. REMOTE INSPECTION SYSTEMS (ADDITIONAL DATA)

NOMENCLATURE	MODEL	WEIGHT	SIZE	POWER REQ.	CONTROL MODES	OTHER FEATURES
Dows	2000	2000 lbs	5'x5' x 8'			Optional bottom scanning sonar. Modular concept design. Remote tool capabilities 500 lbs payload.
Sea Surveyor	DR-32	385 lbs	32.5"x 24"x 131.5"	115 VAC 50/60 Hz 4 KVA	Ship, shore, helicopter or plane by radio link or umbilical cable from surface.	Six axis control, motion picture, 3 dim. TV, and recovery line options.
Remote Vehicle	Busch	147 lbs	24"x28" x 44"	110 VAC 60 Hz 3 KVA.		May be towed at 6 kn. Surface ship or helicopter deployable.
RECON	II	620 lbs	32"x 38"x 42"	3 phase 60 WF 220 or 440 VAC		Pan and tilt TV with 250 W. light Manipulator
SCAN					Remote control from surface.	Crawls along ship bottom with hydraulically powered wheels. Uses positive buoyancy to hold against ship bottom. The TV camera set at oblique angle and one 90° to hull. Can inch forward for detailed viewing.

SECTION 4

CONCLUSIONS AND RECOMMENDATIONS

Underwater inspection in general is a well established field. The greatest progress appears to have been made in the field of offshore petroleum structure inspection. Other countries such as Norway, Sweden and France appear to be the most advanced in this specialized area.

There are many different underwater television systems which may be well adapted for underwater inspection. Low light level and high resolution television systems may be of great value, especially in very dark murky water. The use of lights results in "back scatter" or reflection of light off the particulate matter. This greatly interferes with clarity and resolution.

UDATS is the only television system known to be developed to Navy military specifications. If other systems prove to be more effective, special developments may be required to insure compatibility with the marine environment.

There are also a wide variety of underwater cameras which could be used for underwater inspection. Some of the systems have been designed for great depths and other special requirements and are excessively expensive. Others are very complex and require a high degree of training and skill to use effectively. Maintenance could clearly be a problem.

The SCAN underwater inspection system developed by Underwater Maintenance Company Limited has many features which appear desirable for the effective and rapid inspection of large naval vessels. The photographic and television cameras are held at fixed distances from the ship hull, forward motion may be accurately controlled. One television camera is angled forward for more rapid scanning and another pointed at 90° to the ship hull for detailed viewing of areas with suspected defects or damage.

Two additions to such systems appear necessary. It is of crucial importance to incorporate an accurate navigation and vehicle control system such that the motion of the vehicle may be accurately controlled and that the vehicles position is known within close limits. It would also be advisable to have coordinate or real time information picked up on the video or photos in order to easily relate them to exact ship structure locations.

There is some use of clear water cones or flooding forward of the camera lenses for use where the turbidity is severe.

The author and Mr. John Mittleman have developed an inspection device for use by divers that permits illuminated, magnified viewing of small areas of underwater structures in zero visibility conditions.

The selection and evaluation of underwater photographic and television systems is a very complex problem that clearly requires team effort. Use in the severe environmental conditions required will increase the problems of operation, maintenance, repair and logistic support. The selection and evaluation team should include experts in engineering, diving, photography, television, human engineering, and integrated logistics.

It is expected it will be very difficult to train technicians with the required skill to effectively operate and maintain photographic, television, remote vehicle and nondestructive testing equipment. It appears probable it will be necessary to create two separate civilian underwater inspection billets, i.e., (1) television and photography and (2) nondestructive testing. Probably both groups could be trained in other general underwater inspection tasks such as measurement of bearing clearances.

Discussions with Navy enlisted and officer diving personnel have consistently stressed the great difficulty of training and retraining enlisted divers with high skill levels in special areas other than diving. For this reason, it will be more realistic to use civilian inspection technicians unless there is some basic change in personnel policies. Similar problems are often experienced by civilian diving lockers. This could best be eliminated by a requirement for diver/inspectors to be under the direct supervision of the diving supervisor. It does not appear probable it would be possible to expect such personnel to be expert in the interpretation of complex underwater inspection data. Generally, it would be most satisfactory to have the data resemble that which would be seen and documented as a result of dry dock ship or submarine hull inspection. Clear, high resolution television video and clear photographs with close up shots of defective areas are commonly used and are well accepted. The decision makers could not be expected to interpret raw nondestructive testing data. It will, therefore, be necessary for the diver/nondestructive testing technician to interpret the data. This is currently the practice.

It would be most effective to evaluate underwater inspection systems in conjunction with a shipyard servicing both submarines and ships. The inspection requirements for submarines in particular is very detailed and complex. The inspection tasks must be realistic in order to select equipment which will be effective for Navy use.

It will be necessary to have individual diver held items of inspection equipment as there are areas where access is difficult such as sea chests and others where a remote wheeled inspection vehicle could not travel. Propeller and rudder inspection are samples of the latter. Evaluation should begin with diver held equipment to insure the most effective possible components for both diver held and remote systems.

The current state-of-the-art survey task should be extended by about two months to allow more time for overseas replies.

Reportedly decision making as to action required as a result of underwater inspection is done by such people as ship engineering officers, dry dock officers, shipyard engineers, owner representatives, Coast Guard Officers, etc.

SECTION 5

REFERENCES

(1) Naval Ships Technical Manual, Chapter 9070, "Drydock Instructions and Routine Work in Drydock," Nov 1972, NAVSHIPS 0901-070-0004.

(2) Discussion with LT(jg) Kevin Cowley, Feb 1976, Ships Engineer, USS FIDELITY, MSO-443.

(3) Phone conversation with Ernest Killingsworth, Naval Shipyard, Charleston, S.C.

(4) Drydock Inspection Report, USS FIDELITY, MSO-443, July 1975.

(5) USCG Ship Technical Manual, Chapter 9070.1, Routine Drydocking.

(6) U.S. Coast Guard Forms CG 2926 and CG 4815.

(7) U.S. Coast Guard Regulations for Inspecting and Certifying Merchant Ships.

(8) Personal experience of D. Wyman as USCG Inspector, 1965-1968.

(9) Maritime Administration, Lawler, "Plan for Development and Evaluation of Underwater Inspection Techniques," Dec 1974.

(10) U.S. Coast Guard Rules and Regulations for U.S. Merchant Vessels.

(11) D.F. Jones, "The Survey Afloat of Large Ships."

(12) N.M. Madatov, "Underwater Ship Repairs," Moscow, 1965, NAVSHIPS Translation No. 1238.

(13) Michael Hughes, Underwater Inspection and Repair of Offshore Structures, OTC 2378, 1975.

APPENDIX A

TRIP REPORT - CHARLESTON NAVAL SHIPYARD - 22-24 MARCH 1976

A trip was made to Charleston Naval Shipyard to gather background information for the Underwater Hull Inspection and Clearning project. Arrangements for the shipyard visit were made through Bill Stamey, diving supervisor at the yard. The visit consisted of discussions with shipyard divers, planning and estimating people at both surface and submarine type desks, cleaning and painting people, and nondestructive testing people. A great deal of background information was gathered and a better understanding of U.S. Naval Shipyard overhauls was gained.

Throughout our two-day visit at the shipyard, we discussed diving activities, underwater jobs accomplished, and tools developed with Bill Stamey and his divers. These discussions were interspersed with meetings with other people in the yard. The following is a description of the jobs and tools with which the Charleston Naval Shipyard divers have been involved.

a. Complete cleaning of a submarine hull and propellers (SSBN) at the end of a yard overhaul (9 to 12 months in water alongside pier). One pneumatic "Acqaclean" brush was used with a wooden paddle used to knock off barnacles. Time required - 9 shifts of 8 hours each with 7 men (6 divers and 1 supervisor) = 504 man-hours. Bill Stamey estimates that the job could be done by the same crew in 5 shifts if two brush units were available. The group also does various partial cleaning jobs, i.e., propellers, 3 feet around the waterline to remove grass, sonar domes, etc.

b. Underwater touch-up painting, using the CEL developed paint. They have done areas up to 15 feet square.

c. Replace propellers underwater. This is a relatively easy job with the hydraulic propeller puller that they have developed. Because no staging is required, it can be done faster underwater than in a dry dock.

d. Install full fittings on nuclear submarines before drydocking so that a continuous flow of cooling water is supplied to the vessel throughout the dry dock period.

e. Inspect a submarine as it is put in dry dock to ensure that the blocking fits.

f. Install blanks on various hull openings for work on valves while the ship is afloat.

g. Inspect vessels for condition of underwater hull area, propeller, sonar domes, etc.

h. Inspect and make repairs in submarine ballast tanks.

i. UDATS inspections of various items have been conducted, a selected group of tapes were borrowed for review here at NCSL. UDATS is used to observe many of the jobs with experts on the surface directing the divers' work on the more involved jobs.

j. Various other repair jobs, such as fairing a damaged propeller blade and replacing sonar transducers, etc., has been done.

Bill Stamey's group is working with Chris Cologer at David Taylor Model Basin in a progressive hull cleaning project. Tests of cleaning and the effect of cleaning on ship's speed will be conducted on a suitably fouled surface ship.

Discussions were held with Planning and Estimating people from both surface and submarine type desks. The contact at the surface type desk was Mr. A.D. Nelson, AV 794-4340, with others in the group joining the discussion. The planning and estimating people attempt to project what type of work the ship will require and how much labor and of what types will be required. "Thin hull inspections" are carried out on older vessels prior to arrival at the shipyard to determine if hull structure replacement will be required. Hull and propeller vibration surveys are conducted to determine the condition of various pieces of rotating machinery on the ship. Appendix 1, a copy of the "Ship System Work Description" (inspection items only) of DEG-6, USS JULIUS A FURER gives an example of the estimating done on the tasks to be accomplished. The man-days and cost estimates are "should" costs if ideal work conditions exist; the actual costs average about 15% more. From the discussion, it became apparent that surface ships are not usually drydocked just for inspection. The usual interval between drydockings is about 4 years which coincides with a major overhaul of the ship. Underwater hull inspections at regular intervals could help to make the planning and estimating more accurate and possibly to allow longer periods between drydockings. The cost of just placing a ship in dry dock was estimated to be $20,000 - $30,000.

The submarine type desk people explained that the inspection and repainting of submarines is more critical than surface ships and that it is usual for a submarine to be drydocked about once a year. Shipyards do the drydocking with major overhauls but in between, ARDM's in conjunction with Tenders do the work. At present, the nuclear submarines are overhauled after 44 months, but a new program will probably extend this to the following schedule: 22 months of operation, 2 months limited availability, 22 months of operation and a major overhaul period. The hulls of submarines are built with high strength steels and, as a result, are subject to cracks. The inspection for these now can be done with eddy current testers which do not require the removal of paint to bare metal. Detailed records of hull welds are kept and areas of discontinuity are regularly checked by ultrasonics or eddy current. Appendix 2 concerns the cleaning and inspecting of sonar domes.

Discussions were held with the Painter's General Foreman, W.H. Hall, concerning cleaning and painting of ship and submarine hulls. At major overhauls, the steel hull is sandblasted to bare metal and then three coats of anticorrosive and two coats of antifouling paint are sprayed (usually airless spray) onto the hull. Epoxy paint systems are most favored at this time. At intermediate drydockings, the hull is cleaned of fouling and defective paint, bare spots are touched up, and the hull is given two coats of antifouling paint. At intermediate drydockings, a "hydroblast," 10,000 psi waterjet cleaning system is now favored by the shipyard because other work can be done within 15 feet of the area being cleaned whereas, when sand brushing is used, it greatly interferes with other work. To clean a hull with the "hydroblast," four machines are used with two men for each unit, individually controlled snorkel lifts are used instead of staging. It takes the eight men about five shifts of eight hours each, i.e., approximately 320 man-hours to clean a ship with the "hydroblast" system. To completely sandblast a hull takes eight machines (ten men) a total of 21 eight-hour shifts, i.e., approximately 1680 man-hours. The complete repainting requires 600 to 700 man-hours (three coats AC and two coats AF). Submarines come into dry dock quite clean, surface ships usually come in fairly clean. While some come in quite fouled, most are sandblasted completely and repainted due to the interval between drydocking.

Discussions were held on nondestructive testing with T.D. Glenn, Department Head, and W.O. Williams, General Foreman (telephone 794-4517) of the department. The four major types of testing done at the shipyard are Radiographic Testing (RT), Ultrasonic Testing (UT), Magnetic Particle Testing (MT), and Dye Penetrant Testing (PT). Ultrasonic testing of welds is increasing because it gives more information and is cheaper than radiography. It's one drawback is that no permanent record such as the x-ray film is produced and thus, the reason why most welds are radiographed. The dye penetrants and magnetic particle testing are used for crack detection. Both ultrasonics and radiography can be used underwater. The shipyard divers have placed film packs on the outside of a hull so x-rays could be taken. In the Navy's Planned Maintenance System (PMS), a great deal of nondestructive testing is being done. In a complete overhaul of nuclear submarines, about 22,000 man-hours of nondestructive testing is being done, about 40% of which is on the hull.

This trip to Charleston Naval Shipyard gave us a lot of information about drydocking, cleaning, and inspecting of naval ships and submarines. The walking tour of the shipyard and the boat tour of the shipyard, floating dry dock ARDM-2, submarine tender, and the Naval Base gave us an appreciation of the magnitude of the U.S. Navy's ship husbandry task.

SHIP UNDERWATER MAINTENANCE, EVALUATION, & REPAIR

(SUMER)

MASTER PLAN

APPENDIX D

WATERBORNE CLEANING

PREPARED FOR

NAVAL SEA SYSTEMS COMMAND

PREPARED BY:

Oceanic Division
Westinghouse Electric Corporation

TABLE OF CONTENTS

D. WATERBORNE CLEANING

D.1 INTRODUCTION

D.1.1 PROBLEM DESCRIPTION

D.1.1.1 Background

Hull fouling and roughening have a major impact on the performance of ships between drydockings. Studies indicate that the speed loss of a tanker at full power can exceed 2 knots,or the required power and daily fuel consumption to maintain a constant reduced speed can increase more than 30 percent[1]. Similar effects have been measured on naval ships. With today's high fuel costs merchant ship operators have found it to be economically effective to clean ships' hulls periodically between regular drydockings while the ships are waterborne.

D.1.1.2 Constraints

This study was undertaken to determine the state-of-the-art, to identify gaps in the technology, to develop needed RDT&E, to determine personnel and support facility requirements, and to recommend implementation action concerning waterborne cleaning of ships' hulls, propellers, sonar domes, sea chests and adjacent piping, and appendages. While some consideration was given to ability to strip a hull to bare metal before drydocking to facilitate drydock usage, it is believed that such operations will have very limited applicability as water quality control measures for shipyard operations become more defined and stringent. Consequently the bulk of the study addresses the problem of cleaning fouling with minimum damage to the antifouling coating.

NOTE: References are listed in Section D.4 (page D-28).

D.2 FINDINGS AND RECOMMENDATIONS

D.2.1 FINDINGS

- Underwater hull cleaning is a well-established practice among tanker operators[2,3] and the more progressive cargo liner operators[4,5].
- The technology of underwater cleaning has developed to the stage that it can be applied to U.S. Navy ships now. In fact, fleet commanders are beginning to use the services of established hull cleaning firms to clean hulls prior to ship deployment.

  NAVSURFLANT[6] - 4 (as of July 1976)

  NAVSURFPAC[7] - Approximately 60 (as of July 1976)
- One cargo liner operator[5] has let an annual contract with a diving company to groom his ships with hand-held, powered brushes each time a ship is in Honolulu, about once a month.
- The best known operation to U.S. ship operators is conducted by Butterworth Systems with a unit known as SCAMP (Submerged Cleaning and Maintenance Platform). There are over twelve licensed stations worldwide. More are being established.
- EXXON International studies[1] indicate the following average net fuel cost savings over a 24-month drydock cycle:

At Constant Speed of (Knots)	21K DWT Diesel ($K)	50K DWT Steam ($K)	250K DWT Steam ($K)
11	31	127	144
12	33	141	161
13	35	157	188
14	38	185	228

  The savings have been achieved with a policy of cleaning hull each time speed at constant power drops 1/2 knot. This occurs about 12 months out of dock, thence every 3 to 4 months until the next docking.
- Underwater hull cleaning equipment has been evaluated at Pearl Harbor Naval Shipyard[8].
- Initial trails with USS HAROLD E. HOLT (FF1074) indicate average annual fuel cost savings at nominal cruising speed to be $86K[9].
- BRUSH KART, a multi-brush unit similar to SCAMP, also is being introduced in cleaning stations worldwide.
- High pressure (6,000 to 10,000 psi) water jets are being used to clean substructures, platform legs, pipelines, pilings, etc. in the oil industry[10]. They are applied by a reactionless gun with a diffuser-shielded counter jet to eliminate back thrust and to protect the diver operator.

D.2.1 Findings

- CAVIJET, being developed by Hydronautics, Inc., offers a lower pressure system (1500 to 2000 psi). Point high pressure is generated by the breakdown of cavitation generated by the nozzle.
- SEA MESH, an explosive net technique for fouling removal proved too difficult to handle and too erratic in results. Further interest has been dropped by MARAD[11].
- Cleaning rates with "average" fouling for the most promising systems are:

SCAMP (Merchant Ship)	17,800 sq ft/hr
BRUSH KART	21,000 sq ft/hr
Diver-held rotary brush	180 - 2000 sq ft/hr
High pressure water jet (single)	180 - 900 sq ft/hr (Lab result only)
CAVIJET (single)	900 sq ft/hr (Lab result only)

- Experimental work conducted at DTNSRDC[12, 13] with various brush cleaning methods, types of brushes, etc., and experience to date with commercial and Navy in-house diver-held rotary brush cleaning of naval ships should permit current preparation of a viable performance specification for hull cleaning contracts.
- Current government appropriation procedures preclude the use of fuel cost savings to offset maintenance fund expenditures from current appropriations for hull cleaning[14].
- A study of SCAMP operations by Alpine Geophysical Associates[15] showed virtually no inorganic matter in discharge water and negligible dissolved oxygen demand by organic matter from heavily fouled ships. As a result of the study Alpine concluded that there would be no threat to the quality of estuarine or harbor waters. Nevertheless, debris catching nets can be and are attached to the impeller discharge at some SCAMP stations[16].

D.2.2 RECOMMENDATIONS

- The Navy should establish a policy, and the necessary appropriation support, to clean ship hulls when a certain threshold (for example, 1/2-knot speed degradation at constant power of the tanker operators) has been exceeded.
- Concurrent with the above, accurate methods for measuring actual fuel savings resulting from cleaning programs should be verified or developed, and adopted, as currently included in the Navy's on-going energy (fuel) conservation R&D program.
- Accurate records of hull cleaning costs and resulting fuel savings should be maintained and evaluated to optimize cleaning frequency criteria.
- Because of ethical constraints on licensors of such systems as SCAMP and BRUSH KART against establishing competing facilities to their licensees in the same geographical areas, cleaning generally should be accomplished by established commercial firms in the principal operating areas under a master contract or contracts.
- If operating patterns warrant, consideration should be given to the establishment of Navy-operated hull cleaning facilities on selected tenders, or other intermediate maintenance activities outside the U.S.
- R&D should be initiated, or commercial development work planned by Butterworth Systems, Inc.[16] followed, to reduce the minimum radius of curvature accommodated by multiple brush systems such as SCAMP, to simplify control systems, and to provide more flexible control systems, in order to reduce the percentage of a combatant ship hull which must be cleaned with diver-held rotary brushes.
- A research program should be established to determine whether high pressure water jet systems or CAVIJET offer superior cleaning capabilities to brush systems in:

  Protection of antifouling coating

  Recurrence of fouling

  Flexibility in tight areas
- Should water jet systems show potential superiority to brush systems in the areas noted above, an RDT&E program should be initiated to develop prototype units of ganged water jets which will match the productivity of brush systems.
- As antifouling system formulations change to provide the desired 5 to 7-year drydocking interval, parallel research programs should be established to develop brush systems compatible with their fouling removal and/or surface protection/renewal requirements.
- Continue the study of the biology of fouling organisms, not only to provide the basis for improved antifouling toxins, but also for improvement in waterborne cleaning methods.

D.3 DISCUSSION

D.3.1 INTRODUCTION

Brush systems are the only method by which waterborne ship hull cleaning operations are carried out today. These vary from relatively simple diver-held rotary brushes to more complex ganged brushes in diver-controlled or remotely controlled vehicles. Other methods which have been tried experimentally are based on high pressure water jets and explosive charges. High pressure water jets may employ either water alone or a grit slurry to achieve varying degrees of antifouling and anticorrosive coating removal as well as fouling removal. At least one system has been developed with ganged water jets to increase productivity. One explosive removal system has been tried experimentally, but with little success.

D.3.2 BRUSH SYSTEMS

D.3.2.1 General Discussion

Brush systems which currently are in use include a variety of hydraulically or pneumatically driven diver-held rotary brush units, BRUSH BOAT, SCAMP, BRUSH KART, and a developmental Japanese automatic underwater cleaning machine.

A major element in the achievement of successful brush cleaning is the characteristics of the brush. Its bristles should be sufficiently stiff to remove the fouling, but they should not roughen, and in most cases they should not abrade the antifouling coating. An exception to the prohibition on abrasion is the Norwegian-developed JOTUN system of antifouling coating which depends upon the periodic removal of a couple of mils of spent surface paint to renew its toxic qualities and significantly extend the time between dockings. Typical brushes for the removal of slimes, grasses, and barnacles up to one quarter inch in diameter range from 10 to 14 inches in diameter and are fitted with polypropylene bristles[13]. A Japanese-developed automatic cleaning machine[27] will use a 0.4m diameter brush with 0.8mm diameter nylon bristles turning at 460 rpm. Stiff steel bristles are reported to be required for the removal of large barnacles and tube worms, but these tend to abrade and damage the paint, hence their primary usefulness is for cleaning unpainted steel sonar domes.

Lightly fouled test panels with paint 3 to 6 months old have been cleaned under laboratory conditions at DTNSRDC, Annapolis to confirm the capabilities of polypropylene brushes[13]. Reports of preliminary evaluation indicate that less than 0.15 mils of paint is removed on each pass. As many as 18 passes were made on a single panel without adversely affecting the paint performance. This is part of the on-going NAVSEA R&D effort. The work must be repeated with aged panels.

Bristle orientation varies from normal to the plane of rotation of the brush, and to the surface being cleaned, to angles up to about 30 degrees to the normal. The manufacturer of BRUSH KART makes a distinction in his literature between brushes which because of their orientation, density, and flexibility tend to deflect and wipe or "shear" the fouling, and tightly packed stiff brushes which remain normal to the fouled surface. The former are said to be adequate for marine animal growth, but the latter also accomplish a superior job of digging weed and grass roots from minute cracks in the surface, thus prolonging the interval between cleanings (see following comment).

D.3.3.1 General Discussion (Continued)

It has been noted by commercial ship operators that subsequent cleanings to the first must be undertaken at much shorter intervals in order to maintain the same degree of hull efficiency. The nominal period between cleanings has been reported as 3 to 4 months by EXXON[1], but a British report[17] indicates cleaning at regular intervals of 1 to 1-1/2 months has been necessary to maintain service speed. It is quite possible that the EXXON and British experience is essentially the same, since EXXON uses a 1/2-knot speed decrement to trigger cleaning and the British report speaks of maintaining service speed.

An explanation for the more rapid growth of fouling after the first cleaning is afforded by tests conducted by the British Ship Research Association (BSRA)[18] as reported before the North East Coast Institution of Engineers and Ship builders[19]. To quote from reference [19]:

"In a study of specimens from ships' hulls using a scanning electron microscope undertaken (by the BSRA) for the Chamber of Shipping, scrubbing was seen to have been more effective on smoother surfaces. Considerable quantities of algae were left in crevices; unicellular and colonial algae remained intact whilst the top, or thallus, of *Enteromorpha* and *Ectocarpus* was torn off leaving the basal part intact. Culture experiments in the laboratory showed that if a plant like *Enteromorpha* is broken off, the basal part can give rise to several new branches where previously there had only been one. Minute pieces of weed broken off during scrubbing and caught among other algae give rise to dozens of new plants. There was also evidence that scrubbing encourages the liberation of algal swarmers. From the fouling point of view then, scrubbing off the algae is like mowing the lawn to promote a more luxuriant growth."

"It is evident from these studies that much remains to be investigated in the biology of fouling organisms and the way in which antifouling toxins work. In the end, however, the criterion of a successful antifoulant (or cleaning method) will be the maintenance of the standard speed."

Reference [17] also stresses the need for the selection of the correct brushes to suit the paint to be cleaned, and the employment of skilled personnel to use them. It indicates that for each 1 mil increase in roughness caused by the improper choice of brushes, or poor brushing technique, shaft horsepower and thereby fuel consumption to maintain standard speed can be expected to rise 2-1/2 percent. That observation is substantiated by the results of a carefully conducted series of trials of a class of intermediate tankers operated by Shell Tankers Ltd. The trials were conducted by the BSRA and reported before the Royal Institution of Naval Architects[20].

As noted in reference [20], required horsepower to maintain 14.5 knots was measured for each of two ships operating at 24,280 tons displacement when newly delivered with a clean, fresh bottom, then subsequently just prior to and subsequent to maintenance drydocking over a period of several years. In each case bottom roughness was measured. A plot of percentages of power deviation from the baseline value (ship A in new condition) vs. mean hull surface roughness values showed some scatter, but was well defined by a trend line obtained from the results of Nikuradze's sand roughness tests[21]. The trend line shows that with average roughness of 6 mils, required power to maintain 14.5 knots will increase at a rate of 2-1/2%/mil of roughness. The BSRA reports that the average roughness of new commercial ship bottoms varies between 6 and 7.5 mils. As the roughness increases to 12-13 mils, which was

D.3.3.1 General Discussion (Continued)

observed in both ships after the first docking and repainting, the rate of power increase of the trend line drops to 1-1/2%/mil. At the roughest condition observed, 24 mils, the rate of increase was only 3/4%/mil. However, it must be recognized that in attempting to achieve clean bottom conditions, roughness will be at the lower level where its increase has a relatively greater adverse effect.

D.3.2.2 Diver-Held Rotary Brushes

Figures D-1 and D-2 show two typical diver-held hydraulically powered rotary brushes. The unit in Figure D-1 is fitted with a diver dead-man switch. It has the added flexibility of a support handle which can be fitted at 90° or 180° from the control handle. These machines operate at speeds from 0 to 450 rpm.

Much of the cleaning of Navy ships to date has been accomplished with diver-held brushes. Navy experience indicates cleaning rates of 180 to 240 sq ft per hour under average water conditions[6.], with rates up to 800 to 2000 sq ft per hour under most favorable laboratory conditions[24.] The Matson Navigation Company[5.] has an annual contract with Isle Dive of Honolulu to groom its ships with diver-held rotary brushes each time they are in Honolulu. The "light touch" applied frequently, roughly once a month, is considered by Matson to be the best overall solution to good fuel economy. All "production" cleaning by SCAMP and similar machines must be backed up by diver-held rotary brush cleaning of propellers, bow bulbs, sonar domes, stems, sterns, sea chests, and similar areas with small curvature and/or tight access.

D.3.2.3 BRUSH BOAT

BRUSH BOAT has a long cylindrical brush which is mounted on a work boat, Figure D-3. The brush extends vertically below the surface approximately 8 to 12 feet. It is most effective on the large flat sides of bulk carriers. Cleaning is reported[22.] to be carried out at a rate of about 26,000 sq ft per hour. This will keep up with the 15,000 tons per hour discharge rate of a VLCC permitting cleaning of most of the ship's sides down to the turn of the bilge as it discharges cargo. It is not a viable system for ships having large transverse hull curvature — e.g., most naval combatants.

D.3.2.4 SCAMP

SCAMP appears to be the most widely used of the high production, multiple brush systems. Developed by Butterworth Systems, Inc., US, and Butterworth Systems, Ltd. UK, it is operated at twelve cleaning stations worldwide by licensees. Stations of particular interest to US Navy operations are those operated by RMP MARINE Services at Long Beach CA. and Norfolk, VA. There also is a station at Cristobal, Canal Zone, and two stations are located in Japan. Additional stations are being planned. Cost to clean commercial ships ranges from \$5 to \$9 per foot of length between perpendiculars for "normal" cleaning[23.]. Normal cleaning includes the sides to the turn of the bilge, the propeller, the rudder, and the bow bulb. Cost to clean flat bottom ranges from 100% to 200% of normal charges. Only about 5% of ships cleaned have more than the normal work done — e.g., have the flat bottom cleaned. The cost to clean naval ships is greater than comparable merchant ships

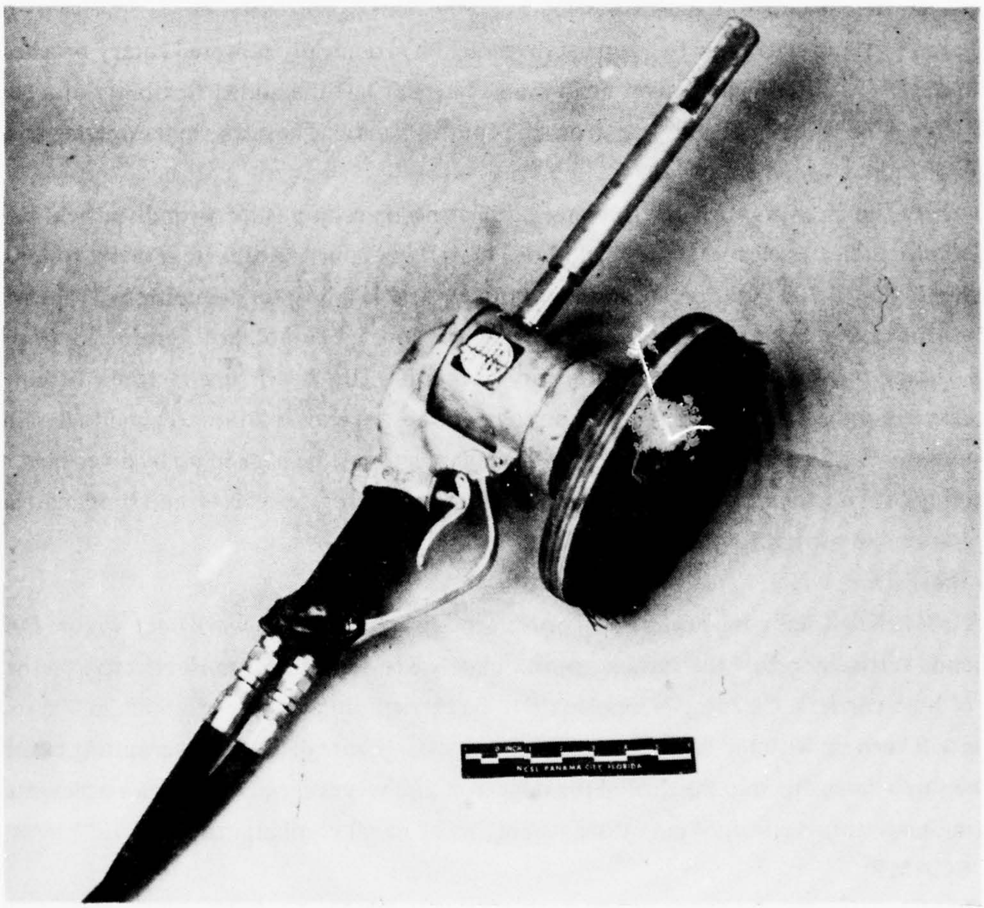

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Figure D-1. Typical Hand-Held Powered Brush With Dead-Man Control Lever

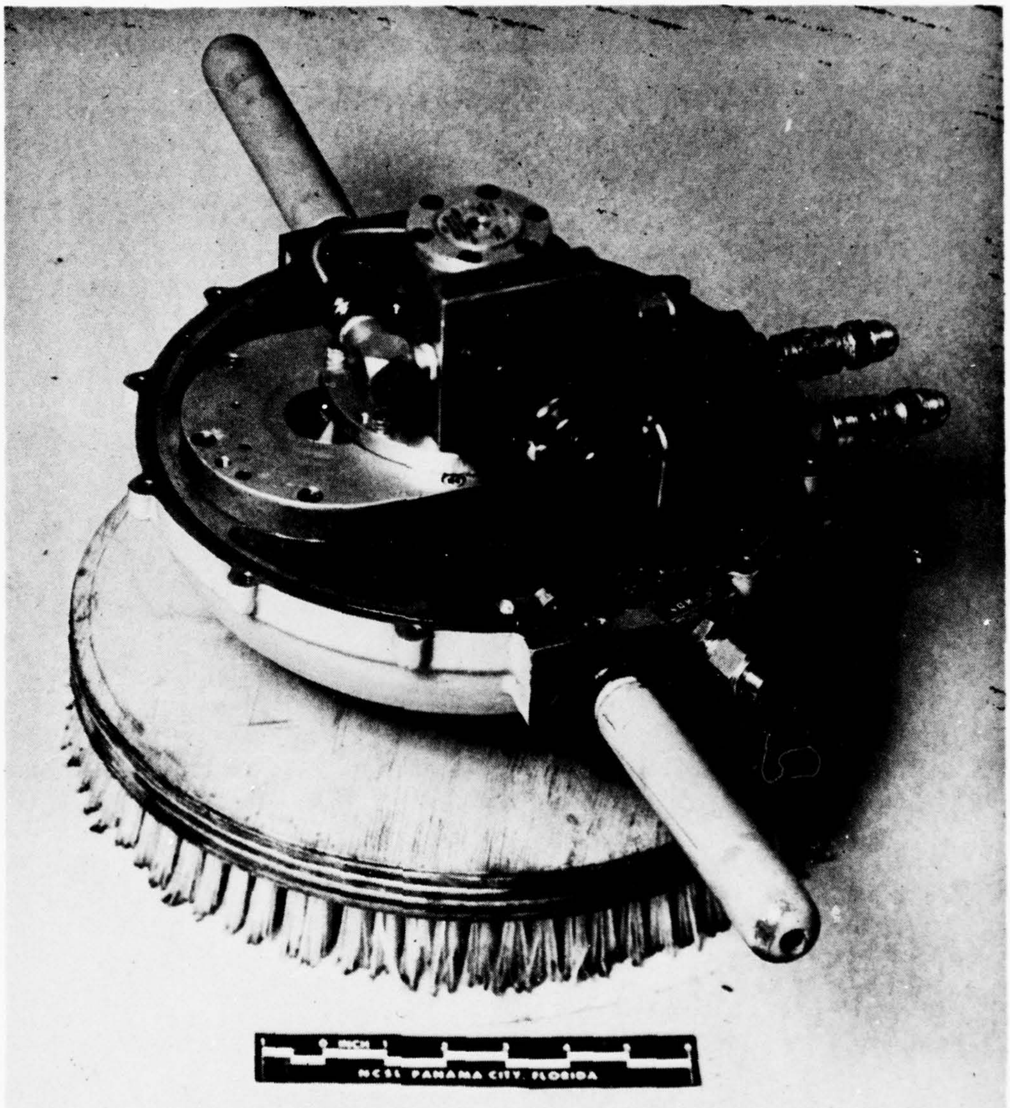

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Figure D-2. Typical Hand-Held Powered Brush With Protective Cover Off

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Figure D-3. Brush Boat

D.3.3.4 SCAMP (Continued)

because the SCAMP unit must be operated under local diver control, and because of the large percentage of diver-held brush work required. It was reported[42] to have been $14,000 or $32 per foot on FF1052.

The SCAMP machine is 6 feet in diameter and 20 inches deep. The underside is shaped like a saucer with a central aperture for an impeller. The saucer shape and the action of the impeller generate a clamping force to hold the machine to its work, Figure D-4. Power is supplied by a 15-HP submersible electric motor driving a duplex hydraulic pump. One unit of the pump drives the impeller while the second unit powers three tractor wheels (one of which provides steering) and the cleaning brushes. Tractive effort of approximately 450 pounds enables the machine to travel at constant speed against most current forces. It travels a horizontal path at a preset speed of 54 feet per minute. The path of the cleaning brushes is approximately 5 feet 6 inches wide given a cleaning rate of approximately 17,800 sq ft per hour.

SCAMP is handled from a variety of small surface craft. Typically at the Bahrain station the tender is a converted trawler. The SCAMP cleaning unit is connected to a control console, Figure D-5, on the support craft by a coaxial cable. Electrical controls on the SCAMP unit are built into a sealed power distribution box. The machine will advance, stop, or reverse either by remote control from the console, or by local diver control. It also can be switched to automatic control whereby it will maintain a horizontal parallel path on a vertical surface. Naval ships, and the flat bottoms of merchant ships require local diver control.

Because of its general configuration, SCAMP is limited to operation on surfaces having a radius of curvature greater than 7 feet (Navy experience indicates the limit may in fact be 10 to 12 feet), and its relatively large diameter prevents its use in tight corners. Although a quick survey of the lines of the new FF indicates over 95% of the hull has greater curvature, experience with FF1052 in San Diego indicates 20 to 30% of the surface had to be cleaned by hand with 40 to 50% of the man-days expended[24]. As noted previously, even on merchant ships, sea chests, bow bulbs, propellers, etc. are cleaned by divers with hand-held powered brushes. Propellers on naval ships are required to be cleaned by hand scraping or rubbing with nylon pads. Sources at Butterworth Systems[16] have indicated that one of their planned development projects is to reduce the minimum radius of curvature of hull surface that SCAMP can work on.

The EXXON International Company has made a careful study of the effectiveness of SCAMP cleaning[1]. Table D-1 taken from the study shows the average speed loss at full power without cleaning over a 2-1/2 year drydock cycle, the percent increase in daily fuel consumption at 13 knots, and the cost ($K) of increased fuel consumption at $75/ton.

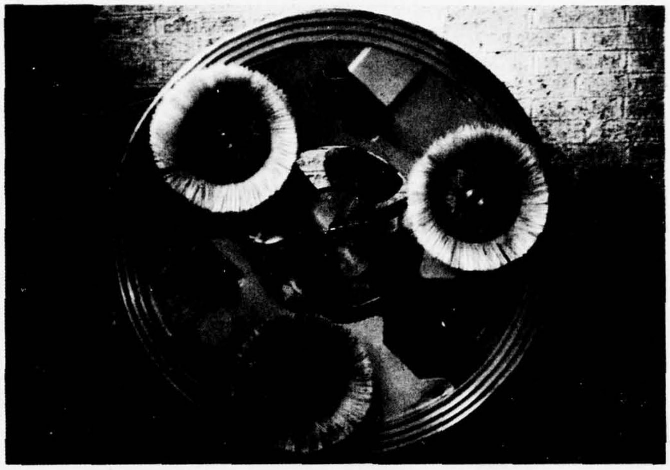

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Figure D-4. SCAMP Cleaning Machine - Bottom View Showing Brushes, Propeller, and Wheels

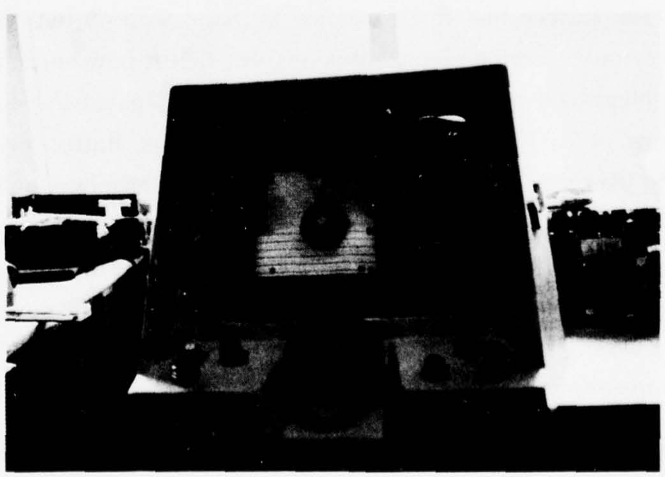

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Figure D-5. SCAMP Control Console

D.3.3.4. SCAMP (Continued)

TABLE D-1.

Tanker Size (K DWT)	Average Speed Loss at Full Power (Knots)	Increase in Fuel Consumption at 13 Knots (%)	Cost of Increased Fuel Consumption at $75/ton ($K)
21	2	42	170
50	2	39	590
250	2-1/4	32	710

The 21K DWT ships were diesel powered whereas the 50K and 250 K DWT ships were steam powered. Table D-2 summarizes the net cost savings from fuel conservation attainable over 24-month docking cycles with SCAMP cleaning undertaken each time speed at constant power drops 1/2 knot.

TABLE D-2.

At Constant Speed of (Knots)	21K DWT Diesel ($K)	50K DWT Steam ($K)	250K DWT Steam ($K)
11	31	127	144
12	33	141	161
13	35	157	188
14	38	185	228

D.3.2.5 BRUSH KART

The BRUSH KART system, Figure D-6, is a French development which is similar to SCAMP. It is manufactured by Phosmarine SA in Marseille. U.S. operations are overseen by U.S. Phosmarine, Inc. of Costa Mesa, CA. Some 21 stations have been established worldwide. Costs in the U.S. are reported[26] to be in line with SCAMP and vary overseas in accordance with the labor rate.

The basic unit is BRUSH KART, a 4.26 foot long by 3.94 foot wide by 1.64 foot high hydraulically powered vehicle fitted with three brushes, and driving wheels to propel it over the surface being cleaned. The vehicle weighs 264 lb in air, but is neutrally to slightly positively buoyant in water. It is held to the work surface by a suction force generated by the action of the three brushes. Brushes and drive wheels are operated hydraulically. Oil is supplied from a surface pump in a closed circuit by means of a coaxial hose. BRUSH KART is reported[25] to be capable of cleaning a 3.9 foot wide strip at 98 to 130 feet per minute. Thus its cleaning rate is 21,000 to 27,000 sq ft per hour. However, the published rate of advance appears rather high compared with SCAMP's 54 feet per minute.

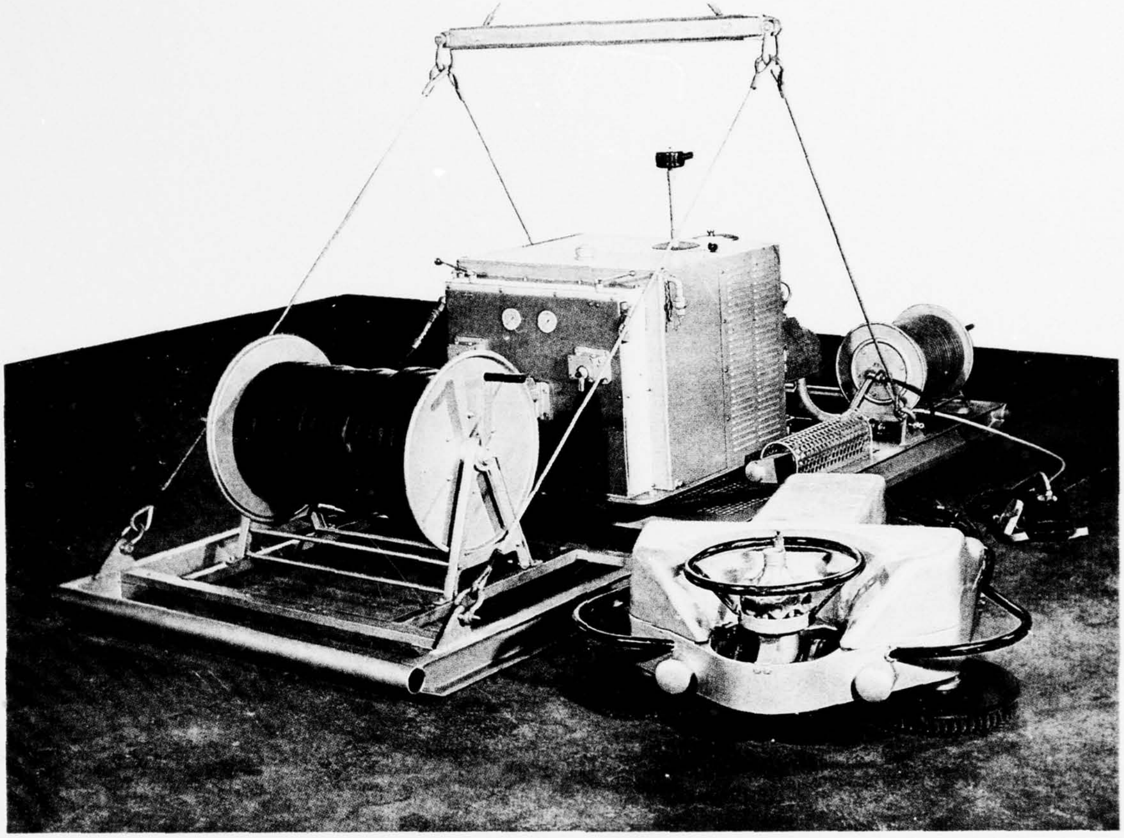

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Figure D-6. BRUSH KART System

D.3.2.5 BRUSH KART (Continued)

BRUSH KART is operated by a diver lying prone on the unit who can maintain directional and speed control with a steering wheel and a lever. Support equipment includes a hydraulic unit capable of supplying one BRUSH KART or two hand-held rotary brushes, a hose winder with 328 feet of floating coaxial hydraulic hose and quick connect couplings, a diver's air supply hose winder with 328 feet of floating hose, and an air pressure reducing regulator for diver air. The complete set of equipment including a BRUSH KART unit weighs 2420 lb and occupies a volume 12.5 feet by 5.3 feet by 5.2 feet. Articulation of the brush mountings permits BRUSH KART to operate on hull curvatures of 6 to 8 feet.[26]

D.3.2.6 Japanese Brush Systems

A Japanese report[27] describes the development of an underwater automatic cleaning machine by Inouye and Co., Ltd. of Yokohama. The single brush unit, Figure D-7, is held to its work by a combination of 3 magnetic wheels and the action of an axial flow pump which draws water through the center of the brush. A unique feature of this unit is a hose which carries the discharge water with removed fouling, paint chips, etc. to the surface where it can be treated in a settling and filtering tank barge before return to its source. The unit weighs approximately 396 lb and is reported to be capable of cleaning 1500 sq ft per hour. Pump and brush power are supplied by a 3.7-kW, 3-phase, 200 Vac, submersible motor.

D.3.2.7 Technology Gaps

There appear to be no significant technology gaps which would inhibit the rapid and effective adoption of brushing techniques to the waterborne cleaning of naval ships. There are, however, development areas which require work to ensure that the ultimate system used will be as cost-effective as possible. In the main, those areas are being covered by the on-going RDT&E program of NAVSEA. They include improved brushes, more effective brushing vehicles, optimization of cleaning frequency, and improvement of underwater visibility to enhance diver efficiency.

In the area of brush technology,work is being pursued by NAVSEA to determine whether a single brush for diver-held rotary units can be developed which will remove all fouling, particularly mature calcareous growth, without causing paint damage.[24] Work also is underway to develop a brush which can be used for propeller cleaning to replace the current time-consuming hand scraper technique. As new paint formulations and methods of application are developed, additional development work will be required to produce the most suitable brush designs for cleaning and renewing their surface toxicity.

In the matter of improved brushing vehicles, the Navy should follow closely and profit by industry's RDT&E efforts. For example, Butterworth, Inc.[16] has two prototype vehicles under test and evaluation which are more simple, diver-controlled versions of SCAMP. They incorporate 50% more power, and have variable speed controls both for the drive system and for the brushes. The control system for SCAMP, which now is based upon 1964 technology, is to be updated to reflect current electronic technology. Development of a more effective remote control system is planned.

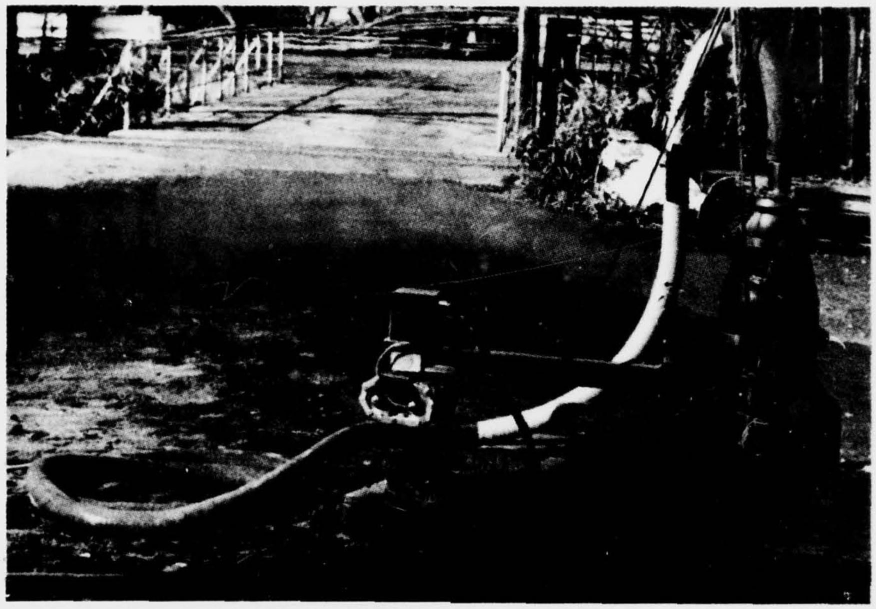

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Figure D-7. Japanese-Developed Automatic Cleaning Machine

D.3.2.7 Technology Gaps (Continued)

Perhaps most important of all, means are to be studied and developed to reduce the current minimum radius of curvature that can be accommodated by SCAMP.

The current program of controlled ship cleaning operations being conducted with COMNAVSURFPAC ships is being closely monitored by DTNSRDC personnel. Out of this work should come basic data to permit the optimization of initial and subsequent cleaning intervals for maximum net return on fuel dollar savings.

As in all underwater work, visibility is a significant factor in the productivity and effectiveness of brushing operations. Thus the wide range of 180 to 2000 sq ft per hour cleaning rate quoted for diver-held rotary brush operations was in large measure caused by varying water clarity. For this reason, commercial cleaning operations have been initiated first in areas having good water clarity, which are reasonably close to major shipping lanes, such as Bahrain in the Arabian Gulf, Tenerife in the Canary Islands, and Cristobal in the Canal Zone. But they also have been installed in major ports such as Rotterdam, Long Beach, Tokyo, and Singapore. Once regular cleaning operations have been initiated on naval ships consideration should be given to the effectiveness of establishing arrangements to improve visibility through such means as wet docks filled with filtered water.

The large amount of RDT&E work already accomplished on brush technology both within the Navy at the DTNSRDC, Annapolis, and by industry, should give ample background for preparing initial operating instructions and/or performance specifications for embarking on a regular hull cleaning program of Navy ships.

D.3.2.8 Environmental Considerations

A survey of the laws of the United States relating to water pollution control and environmental quality[28, 29, 30] and inquiries made of dry dock operators[31, 32] and government agencies[33] reveal no regulations that would specifically inhibit or prohibit brush cleaning operations. However, discussion with representatives of the Army Corps of Engineers and the Chief Plant Engineer of Todd Shipyards indicates that the situation is "fluid" to say the least. At the request of the San Diego Regional Water Quality Control Board, the National Field Investigations Center — Denver, of the Environmental Protection Agency conducted investigations of SAN Diego shipyards from March 18 to April 5, 1974[34]. The purpose was to develop a model National Pollution Discharge Elimination System (NPDES) permit for San Diego commercial shipyards. This is in accordance with a requirement of the Federal Water Pollution Control Act Amendments of 1972 that all point sources discharging to the waters of the U.S. apply for a NPDES permit. The model permit addresses the sources of pollutants from shipyards; the kinds of solids such as blasting abrasives, dry paint and primer, and marine fouling organisms that form the bulk of the pollutional material which may be either suspended or settleable; and monitoring requirements; but does not specify any acceptable level of pollutants — in effect implying a requirement for a zero level. Studies currently being performed by Hittman Associates of Columbia, Md. for EPA may give more precise guidance.

D.3.2.8 Environmental Considerations (Continued)

In any case, brush cleaning will not generate the quantity and kind of pollutants associated with general shipyard drydocking operations. A study has been made for Butterworth, Inc. by Alpine Geophysical Associates, Inc.[15] of the effect of SCAMP hull cleaning on water quality. The investigation consisted of three phases:

1. Calculation of the hydraulic characteristics of SCAMP
2. Scrapings of fouling organisms from two vessels just raised in drydocks and laboratory analysis of the material removed
3. Water sampling and analysis and visual observations during the actual cleaning of three vessels by SCAMP in the Canary Islands. (Those vessels were reported to be very heavily fouled.)

The study findings were that the highest suspended solids content in any sample was 4 mg/l immediately in way of the SCAMP discharge. All other samples in the work area contained 2 or less mg/l. The highest biological oxygen demand (BOD) level observed was 0.9 mg/l over 3-1/3 days at 22°C, barely above that normally expected of "clean" seawater. Coliform tests showed only that whatever coliforms were released by the cleaning operation did not affect the numbers already present, within the tolerance of available test methods. The investigator concluded that the operation of SCAMP poses no threat to the quality of the waters of any estuary or harbor.

It must be noted, however, that SCAMP as applied in the above tests was designed to provide minimum disturbance to the antifouling paint film. Consequently, only minute particles, if any, of toxic compounds of concern in the shipyard pollution study would be present. If at some later time antifouling systems of the type designed to have several mils of surface material removed periodically to renew their toxicity are adopted, the effect of SCAMP cleaning on water quality would have to be re-evaluated. In that case it might become necessary to modify the system to provide for treatment of the SCAMP impeller discharge prior to disposal, as planned in the Japanese system reported above.

D.3.2.9 Personnel and Facilities Requirements

As indicated in reference[17], effective waterborne hull cleaning operations are highly dependent upon the employment of skilled diving personnel to carry them out. Great care must be exercised to achieve adequate fouling removal without damage to the coating. If cleaning operations are contracted for, there will be essentially no demand on the Navy to train personnel for the operation except for a cadre of diver-qualified inspectors to ensure that contractors are in fact completing their work in conformance with specification requirements. However, should the Navy decide to develop its own cleaning facilities, and be able to lease or purchase SCAMP or BRUSH KART systems, operating crews would have to be procured and trained in diver-held rotary brush as well as SCAMP and/or BRUSH KART operations. Contract agreements for procurement of the latter systems should include the establishment and operation of training facilities.

D.3.2.9 Personnel and Facilities Requirements (Continued)

Although it was reported[16] that SCAMP operations have been conducted by as few as two people, one launch operator and one diver, such an operation could not be tolerated by the Navy. A minimum crew to operate a SCAMP or BRUSH KART unit, either commercially or Navy in-house, on a Navy ship would be a launch operator, a console and/or handling gear operator, a line handler, and three first class divers thoroughly trained in the operation of the equipment.

Minimum facilities requirements are a workboat to carry the power supply for diver-held brushes and/or SCAMP or BRUSH KART, diver air, handling gear for power umbilicals or hoses, handling gear for the SCAMP or BRUSH KART units, the SCAMP console if that system is used; and a pier or mooring for the ship. As indicated earlier in the discussion a converted trawler is the workboat at the Bahrain SCAMP station. For most situations it is probable that a workboat at least the size of the 56-ft Landing Craft would be desirable for Navy operations. Operations can be conducted either at pier side (on the side away from the pier) or at a mooring. If SCAMP is to be used for bottom cleaning there should be sufficient water depth (10 feet or greater) under the keel to prevent the impeller discharge from stirring up bottom mud and increasing water turbidity. Four to five feet clearance was found to be inadequate at Norfolk[6] to prevent disturbing loss of visibility in one cleaning operation. Cleaning operations have been carried out under a wide range of water clarity. Obviously clear water greatly enhances productivity. Therefore, the location selected for the establishment of a cleaning operation should have the least turbid water practicable within the constraints of proximity to normal operating areas, freedom from other environmental constraints such as sea conditions and water depth, and minimum disturbance from or impairment to other ship operations. As the practice of hull cleaning becomes more general in the Navy, it may prove economically desirable to provide special wet basins with simple curtain walls to retain filtered water for maximum visibility and minimum environmental disturbance of the operation.

D.3.2.10 Summary

In summary, waterborne hull cleaning operations by brushing have become well established in the civil sector. The techniques and equipment are readily available to serve the Navy's needs. A well structured program based either on contractor support, the establishment of hull cleaning facilities and operating personnel in key Navy installations, or a combination of those two approaches can be initiated at the Navy's will.

D.3.3 WATER JET SYSTEMS

D.3.3.1 General Discussion

Water jet systems, either with the water acting alone, or with various slurries of grit introduced to accelerate the cleaning or stripping action have been well established as a means of cleaning land structures for some years. Diver-held single jet units now are being used for underwater cleaning operations to remove marine growth from substructures, platform legs, pipelines, pilings, etc.[10.] A European-developed ganged jet system, designed to clean ship's sides to the turn of the bilge, has been described recently in the technical press[35.] and in company literature.[36.] Jet pressures range from 6000 to 10,000 psi for cleaning fouling. Higher pressures, on the order of 20,000 to 40,000 psi, have been used experimentally to clean steel to bright metal without the addition of abrasives.[37.] The metal surface of test plates examined by R. T. Miller was actually etched at the higher pressure. Plate cutting has been accomplished experimentally with jet pressures of 90,000 to 110,000 psi. At the other end of the scale experiments have been performed by Hydronautics, Inc.[38.] using a relatively low pressure (1500 to 2000 psi) cavitating water jet to clean marine fouling.

D.3.3.2 High Pressure Water Jets

High pressure water jet cleaning units, high pressure pumps, hoses, and other accessories are available from several sources. These include:

Weatherford/AAI, Houston, TEX

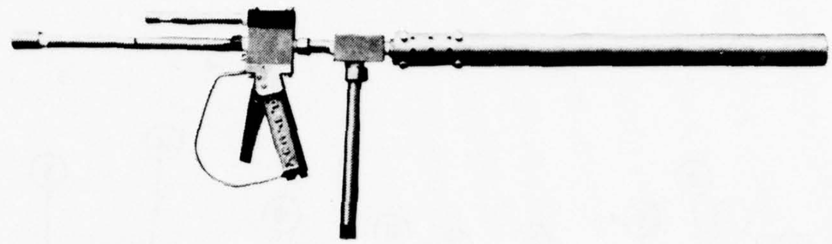
PARTEK Corp. Houston, TEX

Fluid Power Sales, Inc. Sparks, NEV

WOMA Corp., Linden, NJ

PARTEK's Zero Thrust Gun, Figure D-8, was adapted from standard land-based units for use by divers in underwater cleaning operations. It is fitted with an opposing jet to eliminate back thrust. The rear nozzle is mounted in a diffuser which dissipates the blast rendering it harmless. Quick change nozzles, Figure D-9, are constructed of stainless steel. They are reported to show approximately a 500-psi pressure drop in 100 hours of operation at 10,000 psi. The nozzles are available either in straight round, or 15° and 65° flat fan patterns. The straight round tip is recommended for hard or brittle deposits, the fan tip for soft or pliable materials. Specially designed piston pumps, such as that shown in Figure D-10, provide water at 10 to 16 gpm and 5000 to 10,000 psi. The HYDROBLAST system of Fluid Power Sales is based on a 5-gpm pump. Other accessories such as high pressure hose, quick connect couplings, skid or trailer mounted prime mover/pump combinations and abrasive tanks and injector units are available to assemble complete systems tailored to specific operational requirements.

Commercial experience of cleaning rates achievable with water jets on underwater structures where they are used could not be obtained. However, an investigation conducted at the IIT Research Institute[19] for the Naval Coastal Systems Laboratory was enlightening as to their potential. The work covered both plate cleaning at pressures of 7000 to 9500 psi, and plate cutting using pressures of 90,000 to 110,000 psi. The parameters addressed in the tests were jet pressure, nozzle size, cleaning rate, jet



Designed specifically for underwater service, the Zero Thrust Gun utilizes an opposing jet to eliminate back thrust. The rear nozzle is mounted in a diffuser which dissipates the blast rendering it harmless.

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Figure D-8. Typical Water Jet Gun With Zero Thrust Jet and Diffuser

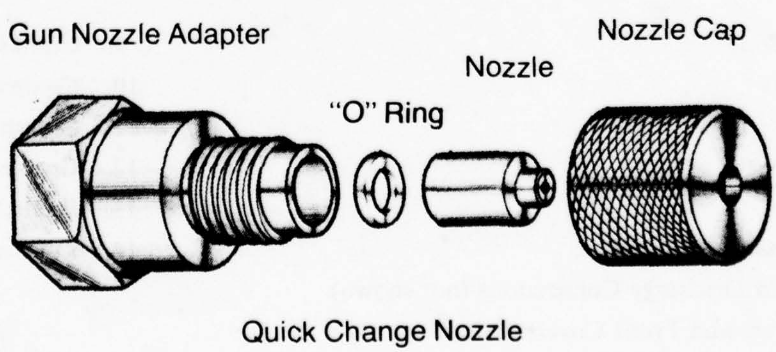

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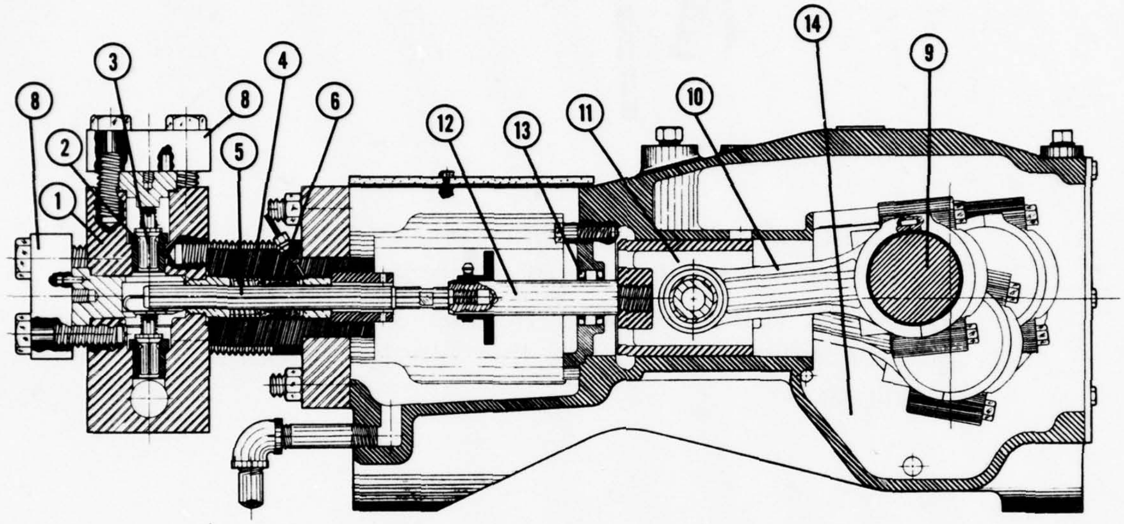
Figure D-9. Typical Water Jet Gun Nozzle



Fluid End

1. Cylinder Body
2. Valve Seats
3. Valves
4. Stuffing Boxes
5. Plungers
6. Plunger Packing
7. Suction and Discharge Connections (not shown)
8. Valve Covers and Front Covers

Power End

9. Crankshaft
10. Connecting Rods
11. Crossheads
12. Crosshead Extensions
13. Baffle Seals
14. Lubrication

76217A10

Figure D-10. Typical Water Jet Pump

D.3.3.2 High Pressure Water Jets (Continued)

angle, and nozzle geometry. Nozzle standoff was not addressed. Cleaning rates of 6 to 12 inches per second, and jet angles of 15°, 30°, and 45° from the vertical were used for cleaning. Both coated (with antifouling) and uncoated plates were tested.

For uncoated plate, the results indicated that a water jet cleaning system should operate at a rapid cleaning rate (e.g., speed of advance), have small nozzle diameters, a low jet angle (e.g., nearly normal to the plate), and an operating pressure "consistent with power availability". For coated plates the tests indicated moderate to severe coating damage with jet angles less than 30° to the normal. At or above 30° the report stated that the marine growth was removed and the antifouling coat remained intact. However, the detailed test data is equivocal on that point in that the comments state "undercoat undamaged" not "antifouling coat undamaged". A call to T.J. Labus, the principal investigator at IITRI, straightened this out. By "undercoat" he meant the antifouling paint coating which was undamaged by jet angles of 30°. Since area cleaning rates cannot be deduced from the report Mr. Labus also was questioned on this. He stated that rates varied from 180 to 900 sq ft per hour with nozzle diameters of 0.4 to 2 mm.

D.3.3.3 CAVIJET

CAVIJET is an interesting variation of water jet cleaning which is being developed by Hydronautics, Inc., of Laurel, Maryland. Tests of the concept have been sponsored by the U.S. Maritime Administration (MARAD).[38] The concept is based on nozzles designed to develop a cavity in the jet. Collapse of the cavity develops local pressures greatly in excess of the discharge pressure of the jet. Thus fouling removal was achieved with operating pressures of 1500 and 2000 psi. In laboratory tests, a maximum cleaning rate of 700 sq ft per hour was achieved with a 1/4-inch jet operating at 1500 psi. The 1/4-inch jet at 2000 psi was reported to have a rate in excess of 900 sq ft per hour. An evaluation of the reported results, however, by the Todd Research and Technical Division, operator of the National Maritime Research Center, Galveston, indicated that the effective width of cleaning path was over-estimated by Hydronautics, so that the claimed area cleaning rate is optimistic. Nevertheless, the results were considered to be promising and continuation of the test program with the following major tasks was recommended.

- Perform further laboratory testing of multiple nozzles on fouled panels
- Conduct underwater tests pressurized to simulate depths up to 100 feet to verify effectiveness as a potential underwater hull cleaning tool
- Develop a design for a carrier mounted system of some type with multiple nozzles.

D.3.3.4 Ganged Water Jet Systems

Woma-Apparatebau of Reinhausen, Germany has developed a multinozzle 6-foot long spray head for hull cleaning, Figure D-11. The head is carried on an electrically driven magnetic wheeled chassis. The carriage is suspended from a crane, or from a special hoist unit which may be fitted at the ship's rail as shown in the figure. Cleaning rates of 43,000 sq ft per hour are claimed with an operating

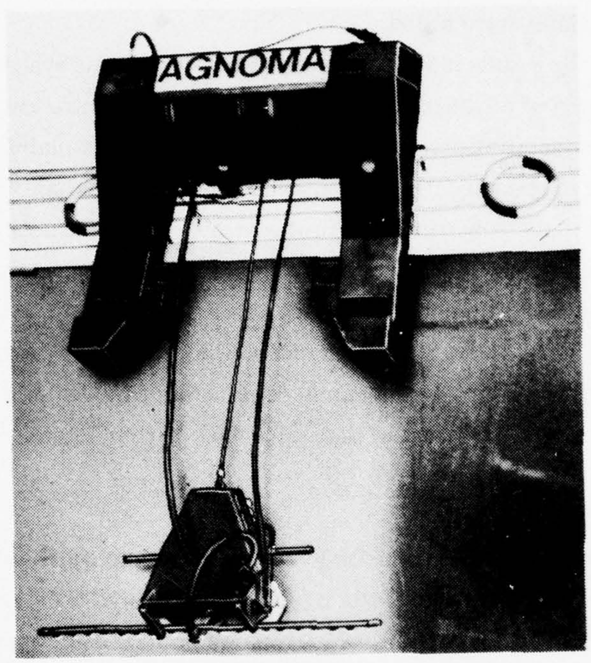


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Figure D-11. Woma–Apparatebau Water Jet Hull Cleaning System

D.3.3.4 Ganged Water Jet Systems (Continued)

pressure of 6174 psi. However, the required advance rate of 119 feet per minute to achieve this cleaning rate appears high when compared with the 54 feet per minute advance rate of SCAMP. Also, the system appears limited in its application to the wall-sided hulls of merchant ships.

D.3.3.5 Technology Gaps

The basic hardware elements are available to build experimental, and perhaps even acceptable prototype water jet systems for the waterborne cleaning of ship hulls. However, with the exception of the two experimental programs cited, there is no body of data to indicate how such a system should be used, or the effectiveness of the results. Water jets may have the potential to clean without abrasive or other damage to the antifouling coating; and, they may be capable of more thorough cleaning action so as to retard the refouling rate as compared with brush cleaning. They have the potential for greater flexibility for access into tight areas such as sea chests. Therefore it is essential that an RDT&E program be established to evaluate thoroughly the effects of jet pressure, nozzle size and configuration, jet angle and nozzle standoff, and nozzle advance rate on cleaning efficiency and coating integrity. Refouling rates should be compared with those of brush-cleaned surfaces. If significant advantages are demonstrated, suitable prototype single and ganged units (for increased cleaning rate) should be designed, built and evaluated; and, operational techniques and/or devices should be developed to ensure maintenance of required jet angles and nozzle standoffs.

D.3.3.6 Environmental Considerations

Environmental considerations for water jet cleaning systems are essentially the same as discussed in D.3.2.8 for brush systems, with one difference. Should the limits ultimately placed upon the acceptable level of pollutants introduced by cleaning systems be lower than that normally experienced in waterborne cleaning operations, it will be more difficult to concentrate and collect the discharge water for treatment as proposed in the Japanese brush system, or used with SCAMP in Japan.

D.3.3.7 Personnel and Facilities Requirements

Personnel considerations and general equipment support requirements for water jet cleaning systems appear to be essentially the same as for brush systems as discussed in D.3.2.9. In either case, a qualified and trained team of divers and support personnel, and a support craft able to carry primary power and diver support equipment are needed. Also, relatively undisturbed clear water will greatly facilitate the operation, significantly enhancing operator productivity.

D.3.3.8 Summary

In summary, the hardware elements upon which to base the development of water jet cleaning systems are available. Either by increasing water pressure or by introducing abrasive materials into the jet stream, as in operations in air, the hull could be stripped to bright metal while still waterborne. However, in the near future, that operation is likely to run afoul of restrictions on pollutants introduced into the water by shipyard operations. Should laboratory tests and field demonstrations of

D.3.3.8 Summary (Continued)

water jet cleaning systems show potential superiority over brush cleaning systems in the protection afforded to antifouling coatings, in reduced fouling recurrence rates, and in greater flexibility in tight areas, an RDT&E program should be initiated to develop prototype units of ganged water jets which will match the productivity of brush systems.

D.3.4 EXPLOSIVE SYSTEMS

A waterborne hull cleaning system based upon a network of shaped charges, SEA MESH, has been conceived and tested. Small scale experiments showed that it is feasible to remove fouling by explosive means. However, prototype tests on several ships have shown the system to be too sensitive to standoff distance of the explosive net, and too difficult to handle precisely even under favorable wave and current conditions to be effective[40, 41]. Considerable shock damage was inflicted on the test ships, and fouling removal was erratic. Therefore, MARAD has dropped further interest in the project[11].

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(SUMER)

MASTER PLAN

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WATERBORNE REPAIR MEASURES

PREPARED FOR

NAVAL SEA SYSTEMS COMMAND

PREPARED BY:

Oceanic Division
Westinghouse Electric Corporation

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E.1 INTRODUCTION

E.1.1 PROBLEM DESCRIPTION

Maintenance of operating efficiency and minimization of repair costs has always been a fact of life for Naval ship operators who must achieve combat readiness within budgetary constraints. Recently, this task has been made more difficult by steep increases in fuel and repair costs, and by the limited availability of drydock capacity. Thus, if the established pattern of ship maintenance and repair is adhered to, costs will escalate rapidly. On the other hand, if maintenance costs are held constant or reduced, as by reduced drydocking frequency, operating efficiency must suffer. Because of these recent trends the Navy is currently considering methods by which most, if not all, types of ship repair may be performed while the ship is waterborne. If this can be accomplished it would likely result in reduced maintenance costs, greater ship availability, and reduction of drydocking requirements. This study is part of the response to those considerations. The main objectives of the study are to define the steps toward waterborne repair which are currently within the state-of-the-art as well as those steps which could be achieved with minimal development. A specific long-term objective of this study is the prolongation of drydock intervals from the current three years to a period of seven years.

E.1.1.1 Background

Current ship maintenance practice calls for drydocking at three-year intervals to clean and repaint the hull. Drydocking is also required for major hull repairs of a permanent nature (such as replacement of hull plate).

Over the past few years, the Navy has made great progress in gradually improving their capability for performing certain tasks underwater such as hull cleaning, propeller changes, and sonar dome repair. In some areas the Navy already has the technology for a more extensive application and its wider adaptation depends only on changes in organization, training, and incentive.

Another major development of recent years is the underwater technology developed by the offshore industry. Some of this technology, with only slight modification, could be adapted for underwater ship repair.

A question of emphasis arises in some instances of adapting existing technology and practice to the present objectives. Much previous underwater work involved emergency repairs or fixes which are only part of the capability which is now being sought. Present technology may need to be extended in certain areas so that repairs of a permanent nature can be effected underwater.

E.1.1.2 Constraints

Certain limitations have been observed in bounding this study and, in general, the same ones will apply in the planning of future actions.

The chief technical consideration was that the technology be available or nearly so, requiring only minor adaptation to be used in ship repairs. Only in cases where technological breakthroughs are required was major engineering development to be considered.

E.1.1.2 Constraints (Continued)

Obviously, repair techniques must also show promise of reducing cost, of increasing ship availability, or of eliminating a drydocking requirement, in order to qualify for consideration. In the case of the latter two features these benefits are only attractive if the cost tradeoff is reasonable.

At present, certain types of underwater work are limited by available personnel, training, and work incentives. It is assumed that these constraints will be modified as the desirability of expanded underwater work becomes apparent. It is also assumed that certain underwater repairs could be performed by commercial contractors if this is attractive for technical, economic, or schedule reasons.

E.2 FINDINGS AND RECOMMENDATIONS

E.2.1 FINDINGS

The major findings of this study are presented below. Each finding is amplified and discussed more fully in appropriate sections of the report.

- Most maintenance and repair work done in drydock can and has been accomplished waterborne - often at less time and expense.
- Tasks which normally still require drydocking are:
  - Stripping and repainting large areas
  - Major repairs to sonar dome rubber
  - Replacing propeller shafts and rudder bearings
  - Major hull structural repairs
- Visibility is a critical factor in the successful completion of all underwater repair and inspection tasks. It is particularly critical for inspection, which accounts for 47% of all maintenance-related dives.
- Partial drydocks, one atmosphere (with access from the surface) cofferdams, and ambient pressure habitats and cofferdams have been designed, built, and operated to provide dry atmospheres for underwater production or repair work.
- Orientation also is a critical factor in the successful completion of underwater repair and inspection tasks. Current aids to divers for locating their position on the underwater hull are crude at best.
- An organized cadre of personnel which collectively would be fully capable of all aspects of underwater inspection and repair does not now exist within the Navy. In general, it has been found more effective to train craftsmen and technicians to carry on their work as divers than to train divers in the more highly skilled trades. Constant practice is required to maintain proficiency in practicing their trade underwater. Suitable training programs and pay incentives are required to assure the development and retention of a cadre of skilled diver/craftsmen and diver/technicians if the Navy is to carry on a meaningful level of underwater repair and maintenance.
- Underwater components such as gratings for sea chest openings, waster sleeves, zincs, fairwaters, dunce caps, rope guards, etc., which are frequently worked on by divers are often welded on and are generally not designed to facilitate underwater maintenance or repair.
- Tools and other equipment such as platforms, lifting and holding devices, which are frequently adaptations of conventional designs, are available now to perform underwater tasks; however, they are in short supply at most repair activities.
- Hydraulic, pneumatic, and electric energy are each used effectively for underwater powered tools, but hydraulic appears best.

E.2.1 Findings (Continued)

- Virtually all of the basic technology required for high quality underwater welds in the dry is available and has been demonstrated in steels similar to MS and HTS. It has yet to be demonstrated in HY-80. However, engineering development of support equipment such as improved habitats and cofferdams for ship work, power transmission techniques, preheaters, etc., is needed.
- Wet welding techniques are available to support emergency repairs to all structure and permanent repair of noncritical structure. Application of wet-welding to permanent repair of critical structures, especially in high strength steels must be approached cautiously. Qualification tests for such applications should utilize a wide range of mechanical tests to seek out any latent hydrogen effects.
- Nondestructive testing (NDT) equipment and techniques for inspection are available. These should be evaluated and standardized to meet Navy requirements.
- Coatings and adhesives capable of being applied in the wet are being developed and have been demonstrated experimentally. Much additional work is needed to make them fully effective.

E.2.2 RECOMMENDATIONS

The primary recommendations of this study are presented in this section. Subsequent sections discuss these recommendations in more detail and delineate their contribution to the underwater maintenance task.

- Review compensation policies and personnel procurement, training, and employment practices to establish the basis for developing a cadre of qualified craftsmen and technicians in selected naval shipyards and tenders to carry on a sustained program of waterborne underwater hull maintenance, repair, and inspection for Navy ships. Develop a plan for initiating these revised employment practices in the Navy.
- Develop ship design standards to facilitate waterborne maintenance and repair operations. Hex or Allen head screws should be used exclusively, vice slot headed screws. Welding should be eliminated as a means of attaching removable items. Sea chests should be numbered to aid in identification, and gratings should be hinged to provide access. Zincs should be bolted on. A hydraulic "Pilgrim Nut" should be used to fasten the propeller to the shaft.
- Develop guides to underwater NDT and inspection. Concurrently with this task, begin an evaluation program to determine which inspection equipment is most effective for Navy use. Such evaluation would aid in obtaining approval for equipment procurement.
- Study overall tool and support equipment requirements and equip key naval shipyards and tenders with a complete stock of NCSL-developed hydraulic tools and power supplies, hydraulic propeller pullers, underwater cleaning and welding equipment, shallow water diving equipment, inspection and other support equipment necessary to effect the full range of feasible underwater repairs.
- Review the requirements for and feasibility of designing and building a family of standard partial docks (such as side-fitting cofferdams to match currently planned bow docks), and both one-atmosphere and ambient pressure habitats and cofferdams for the performance of underwater work in the dry.
- Investigate the feasibility of improving visibility for inspection and repair tasks by the development of localized pockets of clear water, or the provision of complete wet docks containing filtered ambient water.
- Develop a navigation system to provide precise position finding on ship hulls for use by divers and remotely controlled vehicles. Evaluate underwater grid lines, frame markings, and numbering systems as methods to improve position finding.
- Continue the development of coatings and adhesives and wet application techniques to improve their quality and ease of application.
- Contract with an appropriate laboratory and/or diving company to complete any necessary additional development work to demonstrate shipyard quality welds in a dry ambient pressure habitat.

E.2.2 Recommendations (Continued)

- An R&D Program should be initiated to upgrade hull welding by the localized cofferdam procedure and to establish process specifications for the procedure. Objective would be the achievement of shipyard quality welds in high-strength steels or a quality level comparable with this level. In developing procedures and specifications special attention should be directed to hydrogen effects. In view of the Navy's prior experience with the technique, this R&D Program should be pursued within the Navy.

E.3 DISCUSSION

E.3.1 INTRODUCTION

Although it can be stated that underwater maintenance is in a rather undeveloped state within the U.S. Navy, no real breakthroughs will be required to expand the existing concept to relieve the drydock problem.

Waterborne maintenance and repair is done to some degree in all Naval shipyards. Tenders also perform the task routinely. Capabilities vary from performing simple tasks using divers and hand tools only to quite complex tasks involving the use of power tools, welding, cofferdams, staging, and electronic inspection equipment.

Certainly the amount of work done on the underwater portions of a ship during overhaul is much less than required by topside and interior systems. Often the underwater task involves only sealing a through-hull opening so that the real repair effort can proceed from inside the ship in a normal environment.

Specific technological advances would make selected tasks easier to accomplish underwater, including painting, welding, and sonar dome patching, for instance; however, these problems can be circumvented by bringing other skills to bear and should not be considered a bottleneck to the program. Design features favoring waterborne maintenance should be incorporated in new ships and integrated into old ones.

The following paragraphs discuss specific areas of underwater repair in some detail. Facility requirements are covered first, followed by what can and has been done in each underwater maintenance field. Recommendations for improvements are made as they arise during the discussion.

E.3.2 FACILITY CONSIDERATIONS

The existing repair/maintenance/docking capabilities of each port should have the greatest effect on choosing it for a regular waterborne maintenance facility. This capability can, with careful planning and selection, be incorporated with minimal changes to current fleet operating procedures.

E.3.2.1 Site Selection

In addition to strategic considerations, which are not covered in this report, environmental factors should be weighed when choosing an underwater maintenance site.

Diver navigation is the most recurring problem encountered in present shipyard repair facilities due mainly to poor underwater visibility, typically in the 6-inch range. Present procedure is to follow marked hogging lines or weld seams to locate an area. This is not completely satisfactory, since in many cases the weld seam cannot be followed an appreciable distance or else there are several similar hull openings in close proximity to each other. A better technique is necessary, particularly on large ships where pinger navigation systems may be practical. The best solution, of course, would be to locate the maintenance site in an area of excellent visibility if at all possible.

A typical problem of this type is presented by the cruiser NEWPORT NEWS which was prepared for mothballing at the Inactive Ship Maintenance Facility at Norfolk Naval Shipyard by having 63 through-hull openings closed by use of underwater wet welding. Most openings were identified from the ships' plans. A thorough diver search revealed additional openings which were not on the plans. After drydocking, two more openings were found. Harbor water visibility at Norfolk Naval Shipyard is on the order of 6 inches. If the deactivation procedures were carried out in clear water where large areas of the hull were visible, these other openings would not have been missed.

A related story involves the tender diver who closed off a critical discharge opening of a submarine by mistake due to poor position finding.

Because of problems such as these, ship underwater maintenance stations should preferably be located in areas of warm, clear water. The importance of good visibility cannot be overemphasized. It is a necessity for work involving large area inspections, such as overall paint condition evaluation, for photography, and for navigation.

Although most harbor water is quite turbid, it should be noted that this situation often improves dramatically within a very short distance away from the activity hub. The 1/2-ft visibility at the hub of Charleston Naval Shipyard increases to 2-3 ft less than 1/2 mile away.

Excessive turbidity also inhibits the effectiveness of underwater damage assessment television system (UDATS) and makes surface preparations for underwater applied coatings difficult. At Charleston shipyard, debris settles on a cleaned surface almost immediately and must be hosed off with a stream of fresh water before applying the paint or adhesive. A possible solution to this problem is presented in section E.3.2.4 of this report.

A water temperature of at least 60°F is preferred for diver comfort. This also aids in curing epoxy formulated repair coatings. Figure E-1 indicates the degree of protection required by a diver for various water temperatures.

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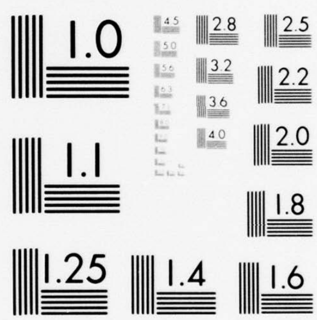

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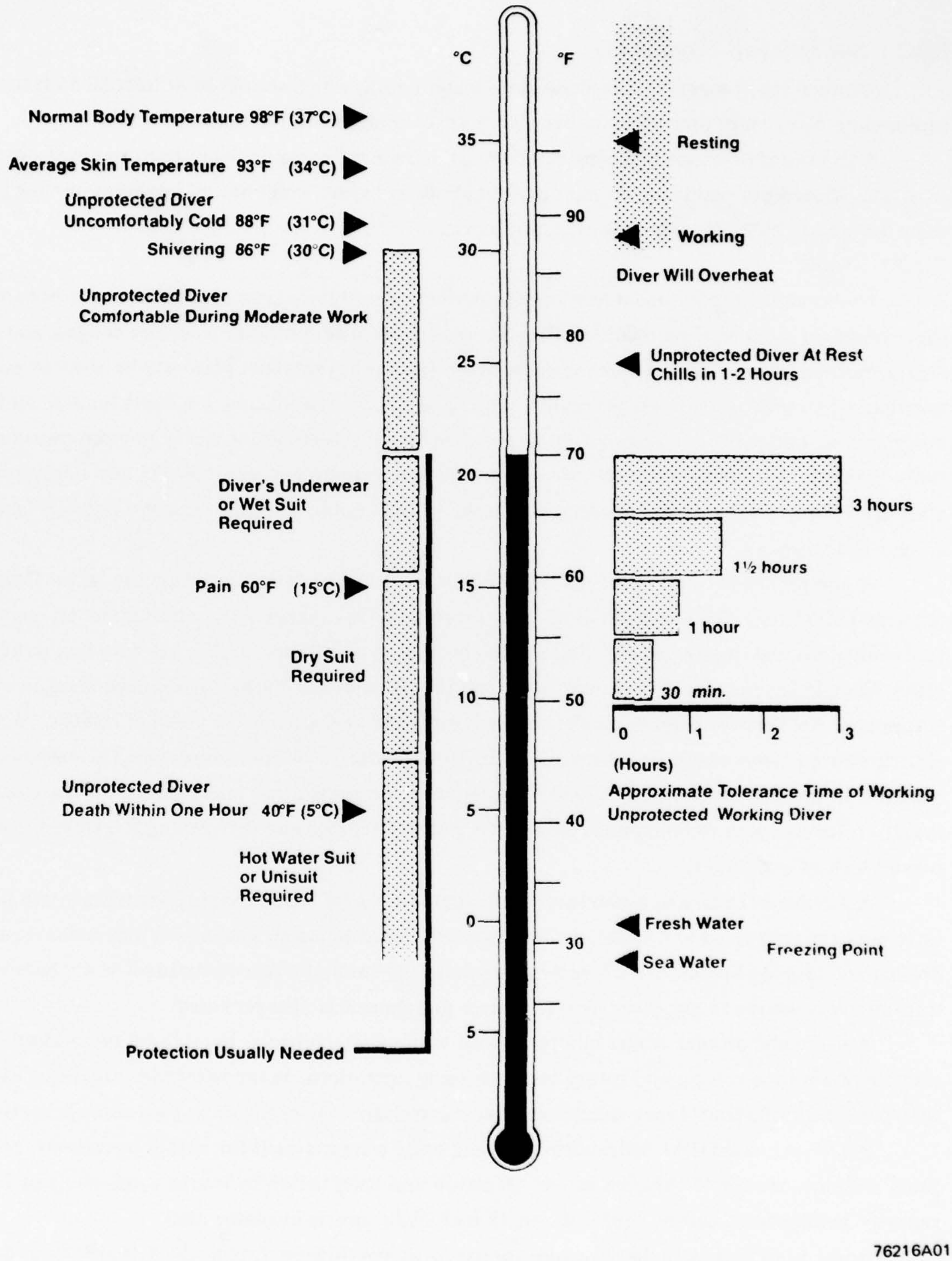

Figure E–1. Water Temperature Protection Chart [13.]

E.3.2.1 Site Selection (Continued)

Another environmental consideration is water depth, which should be at least 50-55 ft to accommodate Navy ships and provide diver work space underneath the hull.

A good tidal flow may be a consideration to flush water contaminated by hull cleaning from the area. This should preferably not create a current above 1/2 knot, which would inhibit swimming and some automatic hull cleaning and inspection devices.

E.3.2.2 Tools

Tools and other equipment necessary to perform waterborne tasks are available now but are in short supply at most existing facilities. Power tools are often adaptations of surface designs, and are for the most part quite adequate for use underwater. Hydraulic tools have proven to be easier to maintain than pneumatic systems, are generally smaller and easier to handle, are not depth limited, are less noisy and do not create a bubble visibility problem which sometimes occurs with open pneumatic tools. Electric tools have the same advantages but are usually not available for use underwater, although they have gained wide acceptance in the Soviet Union. They do present a potential shock danger to the divers.

A comprehensive diver tool package (Figure E-2) has been developed by the Naval Coastal Systems Laboratory (NCSL) in Panama City, Florida.[15*] This has been assembled under an ongoing tool evaluation task begun in 1967. Sixteen kits have been distributed to the fleet with two more on order. Canada has purchased four more sets. Cost ranges from $20,000 to $50,000 depending on what is supplied. An electro-hydraulic power supply is preferred and provides 15 GPM at 2000 psi. Where electric power is unavailable or inadequate, as on some tenders, a 24-horsepower diesel prime mover is available at an additional cost of $7000. Smaller, more portable diesel and gasoline units are under evalution for use with mobile units. Gasoline is not favored because of the danger involved and its overall lack of availability.

A number of hydraulic power tools are available in the NCSL kit. Impact wrenches in two sizes, up to one-inch socket size and up to 1-1/2 inch socket size are included. The smaller unit is also used for drilling and tapping operations, where it is considered to be superior to a normal drill motor because it transmits less torque to the diver. A screwdriver attachment is also provided.

A hydraulic grinder comes equipped with various attachments. In addition to grinding, it is capable of abrasive cutting and rotary brush cleaning operations. In the latter capacity, fitted with a wire cup brush of about 4-inch diameter, it is used to clean small radius areas such as propeller hubs.

An 80-psi, 400-GPM hydraulically driven water pump is used for jetting operations, and is fitted with a balanced "T"-shaped nozzle. A piston and lever action hydraulic come-along of 2-ton capacity pulling force can be supplied. An 18-inch chain saw is available also.

Some tools require higher hydraulic pressures at low flow rates, typically 4-10,000 psi and a 0-10 cubic inches per minute. This combination requires use of a "pressure intensifier" unit to increase

*NOTE: References are listed in section E.4 (Page 56).

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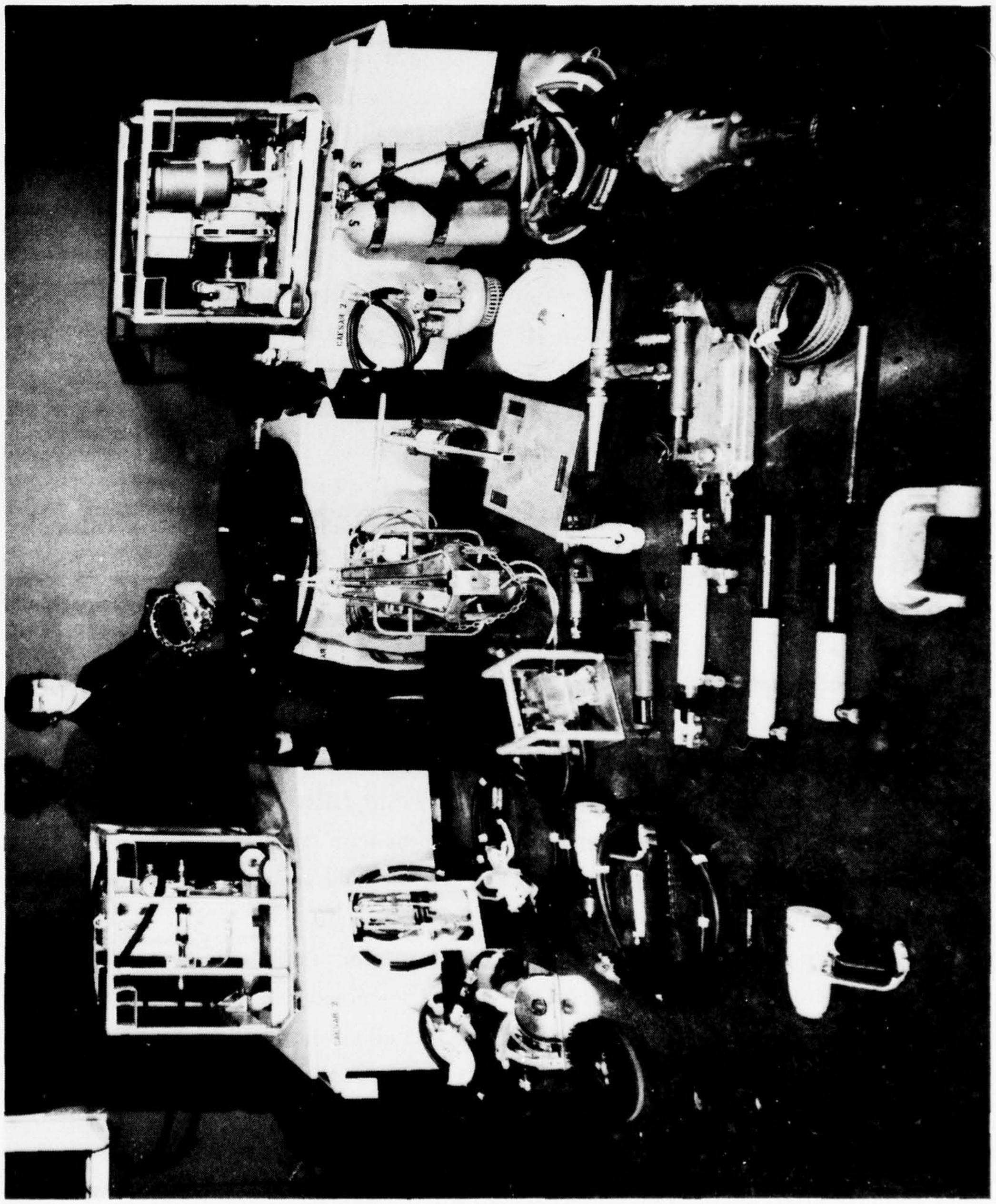

Figure E-2. NCSL Developed Hydraulic Power Tools

E.3.2.2 Tools (Continued)

the pressure output of the power supply, usually in the 1500-2000 psi range. Two models of such a unit are available. A diver-operated hand pump, specially developed by NCSL, can also provide these pressures.

Tools which use this power input and can be supplied by NCSL include barstock cutters up to 5/8-inch diameter capacity, single acting jack rams of 6-inch and 10-inch extension, a wire rope cutter which can handle up to 1-1/8 inch diameter, a self-contained 5-ton lifting jack, and a 10-ton pull cylinder with 10-inch stroke. Various attachments are available for the rams, including a "C" clamp pincher and "duck bill" spreader plus assorted bases and extensions.

A 750-pound capacity constant buoyancy lift bag has been developed. The 2-foot diameter, 5-foot long cylindrical bag is laced to a circular lifting ring at the bottom and is equipped with a waterproof zipper extending down its length. A standard scuba bottle is mounted on the ring. By setting the zipper at the required length, and keeping air bubbling out the bottom, a constant buoyancy level up to the maximum capacity can be maintained.

Another tool suitable for use underwater is a blind bolt fastening tool. Working similar to a pop-rivet gun, it uses hydraulic pressures of up to 10,000 psi and handles bolts up to 1/2-inch diameter.

A Hurst automobile hydraulic rescue tool has been modified for use in seawater. This tool has two 36-inch arms which can open through 32 inches and provide 5 tons of force in either direction.

A commercial RAMSET stud gun which can fire studs into steel plate is useful mainly for salvage or retrieval tasks. These guns must be pressed against the working plate before they can be fired, as a safety feature.

Other tools include hydraulic cable cutters to 2-inch capacity and nut splitters for removing corroded fasteners. A water inductor that can be used to suck up large amounts of sediment, and a "hot tap" machine which can make connections into pressurized pipe or ship cargo holds are available, as are hydraulic and pneumatic rock drills. Civil Engineering Laboratory (CEL) Port Heuneme has developed several other power tools including a hydraulic hand-held band saw.

All manner of hand tools can be used underwater the same as in air including wrenches, screw-drivers, chisels, hammers, saws, block and tackle assemblies, etc.

There is still a need for some specialty work tools to be developed. These should be defined and evaluated under a program such as that at NCSL. A need has already been expressed for such tools as a hydraulic saber saw for cutting No-Foul rubber, and a small power brush for propeller and sea chest cleaning. An acceptance procedure for getting such tools into the field once created is also required.

E.3.2.3 Support Equipment

E.3.2.3.1 Diving Gear

The existing diving lockers should be equipped with the best equipment currently available. Diving-related gear, which up to now has been generally neglected due to shoestring budgets, is currently in short supply and should be upgraded almost across the board. This task has reportedly already been initiated, and should be continued, under NAVSEA Director of Ocean Engineering direction. Diving air compressors must be standardized and made more readily available.

E.3.2.3.1 Diving Gear (Continued)

Umbilical air supply dive gear is generally preferred over scuba since it is less bulky and is not time limited. The Jack Brown masks are most useful, being the lightest and simplest system. Where communication or welding is required USN Mark I or Kirby-Morgan masks and dry Unisuits are used. Scuba is useful for inspection or working around propellers and rudders or other areas where umbilicals may get in the way. For the hull maintenance task, there is no use whatever for the old hard hat deep diving suit. Many facilities do not now have a dive boat or have an inadequate one. Dive boats should be large enough to provide shelter for the work crew and store all maintenance equipment including the hydraulic power supply and diver air compressor. An electrical generator is a necessity. A smaller "helper boat" is a good accessory, useful for running supplies and doing small tasks such as setting hogging lines.

E.3.2.3.2 Work Gear

A full assortment of hand and power tools, including hull cleaning units, should be a part of the diving locker. Inspection equipment including UDATS, color still photography, ultrasonic thickness gages, and radiography and eddy current weld test units should be included as well as the educated capability to use and interpret these systems. Docking plans identifying ship hull characteristics and item locations should be available. Careful records must be kept of all inspections and work done on each ship, and these must be made available to other facilities. A supply of commonly used patches and sealing flanges should be stocked.

Platforms and staging equipment necessary to do maintenance work may be assembled the same as for drydock operations. These are held to the hull by means of hogging lines. "Bearpaw" magnets, which provide about 250 lb of holding force, may be used to help position staging and support equipment. Staging of some sort is required for bracing oneself and for tool storage for all but the most simple tasks. As a general rule, if the equipment to be used weighs over 10 lb in water, and if the time required to do the job is over 20 minutes, then a work platform should be provided.

E.3.2.4 Enclosures

E.3.2.4.1 Cofferdams

Because of the nature and frequency of sonar dome repair work, efforts have recently been expended toward developing a very large cofferdam, really a partial drydock, that would cover the bow area and be versatile enough to fit as many classes of ships as possible. Bath Iron Works Corporation in Bath, Maine has developed a unique bow dock of this type featuring special fixtures at the after end for mating with different ships.[25]

The naval architecture firm of J. J. McMullen recently completed preliminary plans for a floating bow dock[24] under NavSea direction (See Figure E-3). It is based on the Bath Iron Works design and is intended to service all present and future ships using the SQS-23, SQS-26, or SQS-56 sonar domes except aircraft carriers. Current plans call for a total of four units, two to be delivered in FY '78 and two in FY '79. One would be located on each U. S. coast, one in Pearl Harbor, and one floating for use as needed.

E.3.2.4.1 Cofferdams (Continued)

The availability of these bow docks to service sonar dome-related problems would free existing drydocks for other uses.

Up to now, most man-rated cofferdams have been built on a per-job custom basis and have been a rather expensive proposition. As such, a need exists for a small movable cofferdam of standard design and manufacture having air access and suitable for manual work on the sides and bottoms of ships. Such a unit would eliminate the life support diving equipment now required to perform work tasks below the waterline. Work involving welding, cutting, grinding, and painting could be done with the same quality and inspection techniques as is done in drydock.

An ideal design would allow various side fixtures to be installed for sealing against different ships or at varying points along the hull. Figure E-4 illustrates a possible concept for a cofferdam of this type.

A similar concept, shown by Figure E-5, utilizes a trapped air bubble instead of air access to provide the dry environment. This design must be held against the hull purely by mechanical means as no differential pressure between the gas and seawater sides exists. It is more suited for use on flat bottoms than on the sides, where an air access unit could be installed as easily. One disadvantage is that in the event of through-hull damage the hole must first be cofferdammed and pressurized from the inside before the bubble could be retained.

Smaller cofferdams, including patches and sealing flanges, are usually designed and built in the field to suit a particular job. This effort could be streamlined if standard designs and sizes were made available to each facility. Other than the floating bow docks, there are no cofferdam-related programs currently under consideration. NavSea investigated the bow dock concept to determine if it could be adapted to a sterndock design for servicing propellers, shafts, and rudders. This idea was abandoned because of the difficulty of sealing around shafts and various hull curvatures. There is also some talk of starting a floating drydock program to service the destroyer fleet starting in FY '80, although no funds have been allocated.

E.3.2.4.2 Clear Water Facility

Water of decent clarity, having at least 2-3 feet visibility, is considered essential to do reliable work underwater. If this is not available naturally, a simple enclosure could be constructed at the servicing dock where the ship would be located during the underwater repair work. One side of the enclosure would open to allow the ship to enter or leave. Water could be either fresh or filtered from the harbor. If the filter cycle was run continuously only a loose seal would be required, allowing water to flow in and out of the berth following tidal changes. Figure E-5 illustrates the idea. The economics of this concept, or one delivering the same result, has not been pursued; however, the benefits in improved working conditions are undeniable. Among the many improvements offered by such a scheme would be more thorough inspections, less patchy cleaning, better quality underwater painting, faster and more accurate position finding and generally improved work performance. In addition, if environmental regulations become a factor, residue removed during the cleaning process could be contained and filtered out without contaminating the outer harbor.

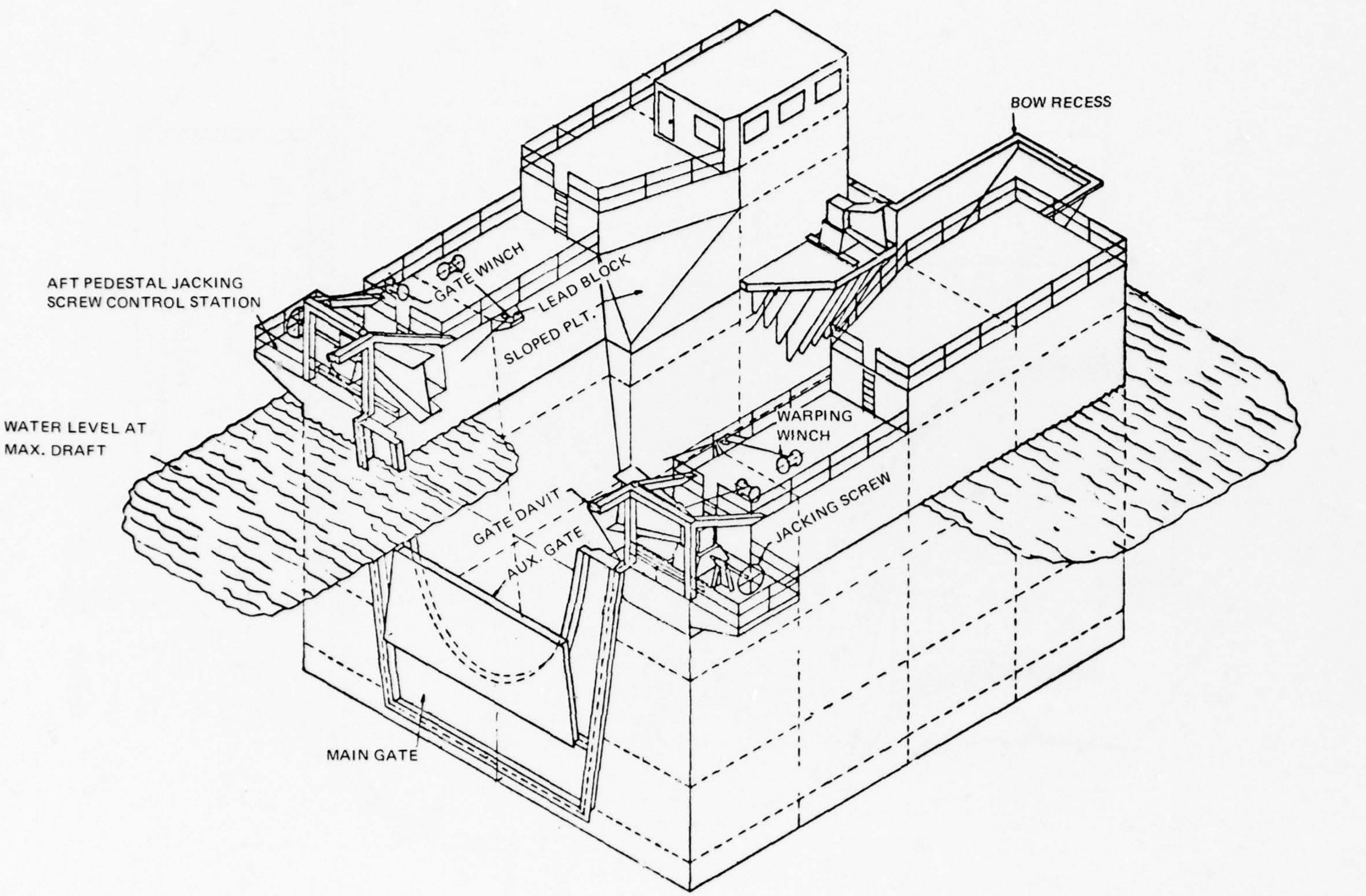

Figure E–3. Baseline Bow Dock Configuration[24.]

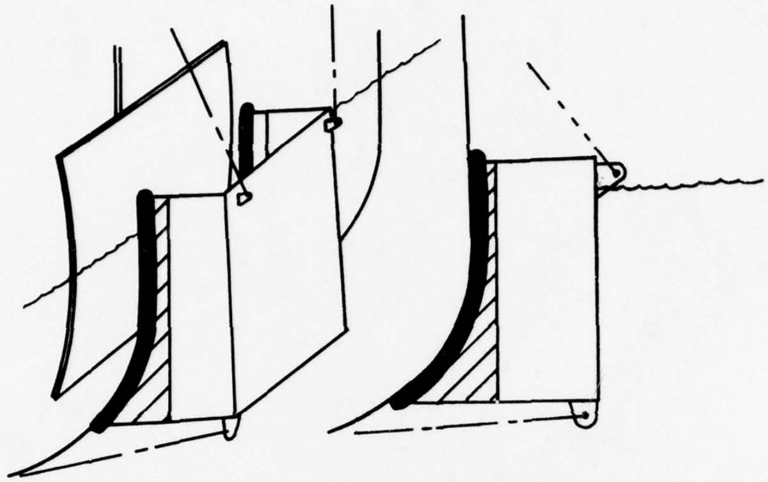

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Figure E–4. Side Fixture Cofferdam

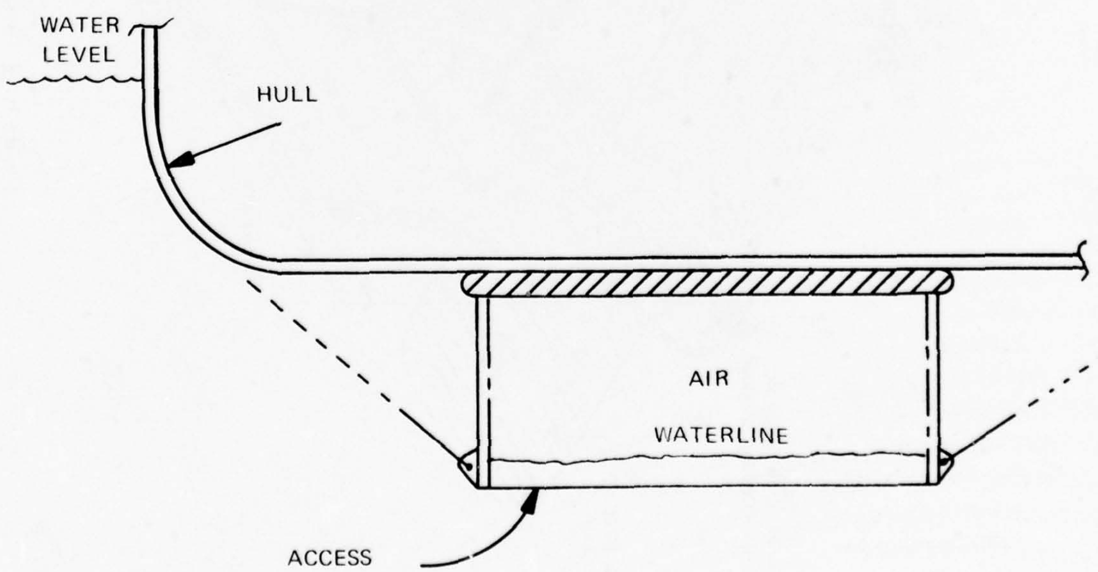

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Figure E–5. Bottom Access Cofferdam

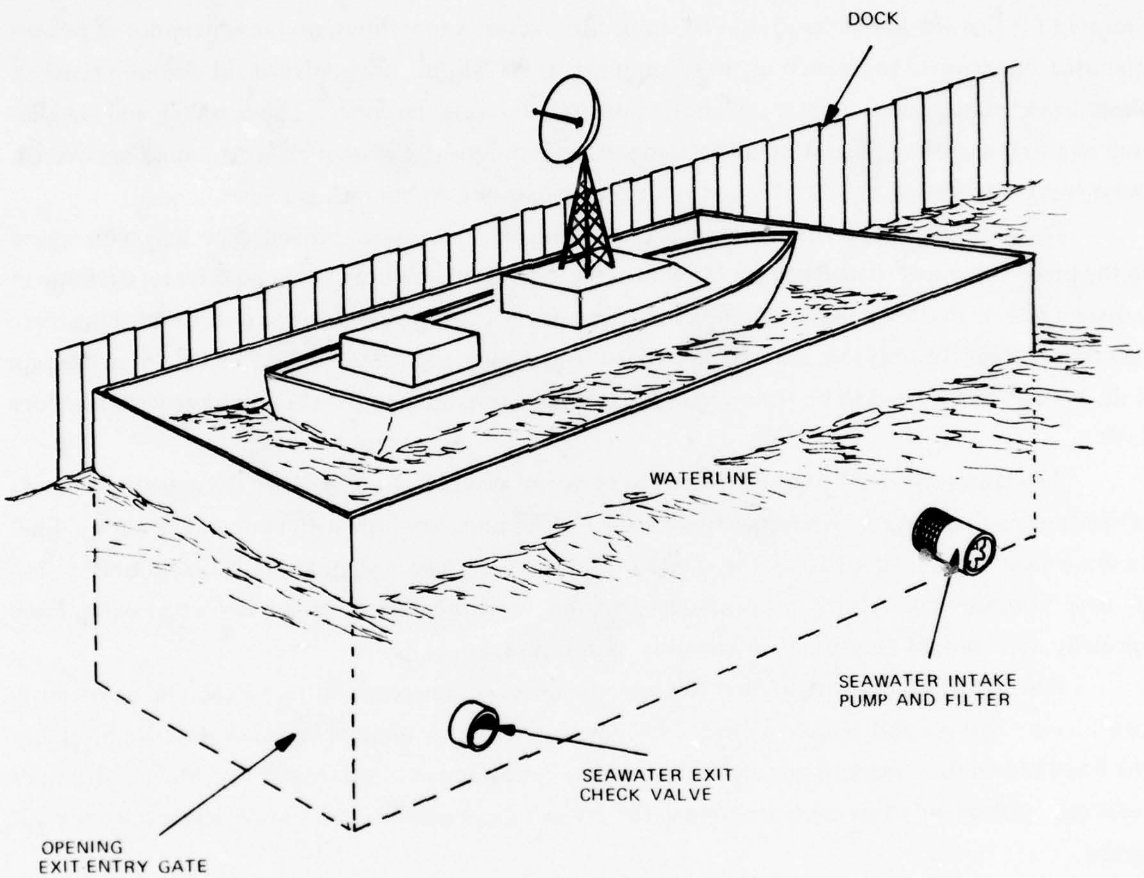

Figure E–6. Clear Water Maintenance Facility

E.3.2.5 Personnel

The implementation of the ship underwater maintenance and repair plan will require additional personnel and a comprehensive training program.

The diving training program should concentrate on shallow water scuba and surface supplied air umbilical systems, with and without surface communications. The hard hat deep diving suit is not required for this work. Divers should be trained in the use, capabilities, and maintenance of power-operated underwater tools such as those supplied by NCSL, including diver-held cleaning brushes. Basic work related procedures should be demonstrated during the course. The handling and installation of patches, sealing flanges, small cofferdams, and underwater work platforms should be covered. A working knowledge of UDATS and underwater painting techniques is recommended.

The incentives to become and remain a working diver must be improved, especially with regard to the present pay scale which neither recognizes the individual's ability nor his experience. Creation of a diver's rate or Civil Service designation for diving has been proposed as a means of establishing these pay differentials. In addition, other diver-related restrictions, such as the BUMED regulation limiting a diver's age to 45, need to be reviewed in light of their relevance to the ship underwater husbandry task.

Specialists will need to be developed to perform certain tasks. The Navy has essentially no experience with underwater nondestructive testing (NDT) and very little with underwater wet welding. In these more highly skilled areas, the choice must be made between whether the Navy should develop its own in-house capabilities or contract with commercial businesses on an as-needed basis. Each specialty area should be evaluated with this option in mind.

With regard to high quality wet welding, the use of commercial contractors should be seriously considered. This is a skill which requires constant practice to maintain proficiency. It is doubtful that the Navy has enough work of this nature to warrant development of this capability. Most underwater weld repairs done on ships could be done in the dry using cofferdams, and should not require any wet welds.

Where shipyard quality welds are not a concern, as for zinc anode or temporary support bracket attachments, a highly skilled diver-welder is not a necessity at any rate.

In addition, there are several competent wet welding commercial concerns which are kept busy with other work, usually on offshore oil rigs and subsea pipelines. This topic is further discussed in section E.3.5.

For those specialty tasks that are to be developed within the Navy (NDT will probably be one) special training must be provided. In some instances, teaching a skilled technician to be a diver may be easier than educating the diver in a skilled trade. Industry usually uses the technician-to-diver approach, although the individual's capabilities and amount of training required should be evaluated on a case-to-case basis.

Some specialists may not require diver training. If UDATS and diver-to-surface communication is available, the specialist may instruct the diver in the performance of a test while reading and recording the results from topside.

E.3.2.5 Personnel (Continued)

The capabilities and location of all specialists should be on a central file so that these people may be deployed as the need arises.

Personnel must record and maintain a careful record of all work done on a ship, including marking the ship's plans, and this record must be made available to all other repair yards.

E.3.3 HULL MAINTENANCE

Work on the hull includes those tasks involving hull plate, sonar domes, bilge keels, sea chests, and paint maintenance. Weld related repairs are covered in section E3.5.

It can be stated that very few tasks involving the hull that are normally accomplished in drydock have not been done waterborne due to deficiencies in actual experience or state-of-the-art. Chief among these are stripping and painting large areas of the hull, repair of major structural damage to the hull, and repair or replacement of large areas of rubber sonar dome windows.

Technology and experience are expected to catch up to the sonar dome problem very soon. Creating dry areas by ballasting, cofferdams, or patches could provide answers to the painting and major weld and repair problems.

E.3.3.1 Sonar Domes

Replacing or repairing steel and rubber sonar dome windows has been a common reason for drydocking in the past. A recent example of this occurred in Charleston Shipyard, where the FF1072 was scheduled for emergency drydocking to repair a 3 ft x 8 ft section of rubber sonar dome material damaged in a docking accident. By using a newly developed B. F. Goodrich two-part patching compound, this area was completely repaired underwater with a manpower expenditure of 80 hours.

This material was used to adhere loose sections of rubber material to the dome and to patch small (under 1 ft^2) holes in the cover ply.

In this particular case, brackets were welded to noncritical areas of the dome, and a contoured fixture was clamped on to apply pressure to the patch. When used as an adhesive, the material must be allowed to cure under pressure, after which it may be sanded to a smooth contour. It does not retain the antifouling feature. To continue advancement of this technology, techniques of cutting away and removing old material and replacing these areas with large sections of new cover ply or sheathing must be expanded. The antifouling and acoustic properties of the original rubber usually last 5-7 years, well within the target drydock intervals; however, the rubber cover ply or sheathing sometimes sustains damage in docking or while underway at sea and it is in the area of repair that the R&D effort should be directed.

Major overhaul or structural damage will still require drydocking. The availability and use of a floating bow dock (section E.3.2.4) will minimize the ship's downtime and free a conventional drydock for other uses.

Smaller sonar units, such as depth pingers and speed sensors may be replaced or repaired underwater with little or no difficulty.

E.3.3.2 Sea Chests

Next to hull cleaning, (Appendix D), tasks involving sea chests constitute the majority of current in-water work. These through-hull openings must be inspected, cleaned, and have their valving and piping repaired. They are sealed as part of the deactivation procedures or to allow work to be done from inside the ship. Typical sea chest locations are illustrated by Figure E-7.

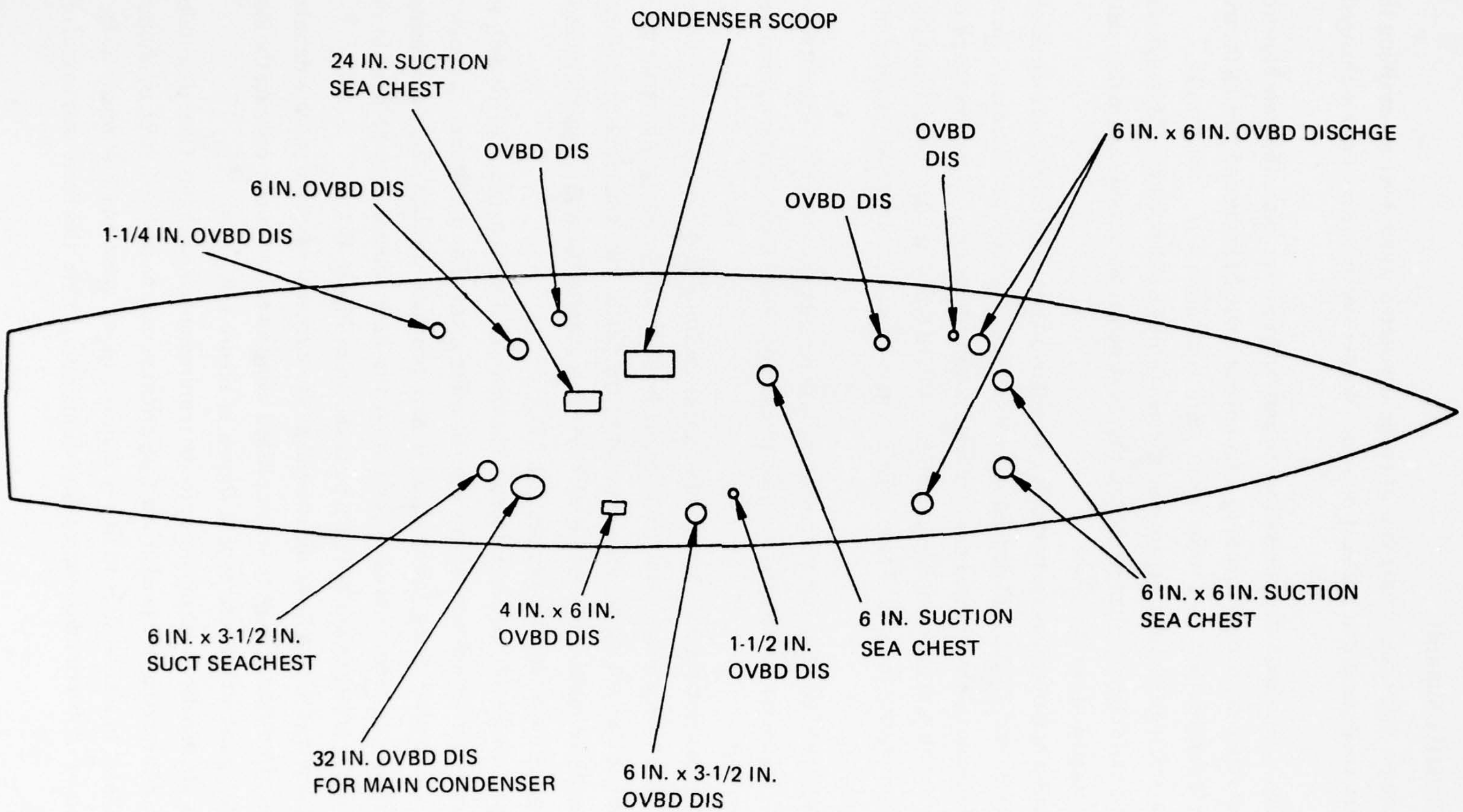

Figure E–7. Typical Sea Chests [12.]

E.3.3.2 Sea Chests (Continued)

By closing a valve, sea chests can often be dewatered using diver air enabling the work to proceed in a dry environment at ambient pressure. Waster sleeves are commonly changed using this technique.

Similarly, submarine ballast tanks may be entered by a diver. Since these are blown dry in port, inspections and repair work can proceed in a dry environment. Splicing and potting the wiring, paint touch-up, anode replacement, and valve repair work is all done within these tanks.

Hand scrubbing and water jets are used to clean through-hull openings. Although water jets are much faster and more effective than scrubbing, they have had mixed reviews due to their cutting ability which may be hazardous to the diver.

Sea suction hull openings are normally covered by an intake grate of some sort. Access through the barrier may be easy or difficult depending on its design. The most suitable design for underwater work is bolted on one side and hinged on the other, allowing the grate to swing down to provide access. Others simply unbolt and are completely removed. A third type is welded in and is not designed with underwater maintenance in mind. These must be cut out using a torch, and rewelded in place after completing the work.

Caution should be observed when working around sea chests to ensure that all suction pumps are turned off. At least one fatality has occurred when a diver was sucked against a grating, lost his face mask, and drowned.

By using patches (small, closed cofferdams), welding and cutting can be done in an air environment. This work must be done from inside the ship, with grinding and repainting operations done by a diver in the wet mode after removal of the patch. This technique may allow first class certifiable welds to be made on the hull while the ship is waterborne, and is a viable method of repair for hull damage of moderate size (see section 3.5).

These patches are of two general types. The first uses J-bolts to fasten to the hull, attaching to gratings or jury rigged attachment points around other areas. The J-bolt may be inside the patch, sealed with a cover after being installed, or it may protrude through the cover using a sealing compound around the hole to keep water out. A fire hose eductor may be used to dewater the assembly. A typical arrangement of this type is shown in Figure E-8.

The second type uses only the differential pressure created when the patch is dewatered to seal itself to the hull. Dewatering may be accomplished using an eductor or by opening the inside area to atmosphere. A typical unit of this type is shown in Figure E-9.

Patches are usually made on-site to fit the requirements of each job. Once assembled, they are kept on hand and reused as the need arises. Construction may be of wood, steel, or aluminum. Units should be available in several sizes to fit the majority of sea chest and hull repair tasks.

Wooden or rubber damage control (dc) stopper plugs have also been used to seal off small sea chest openings.

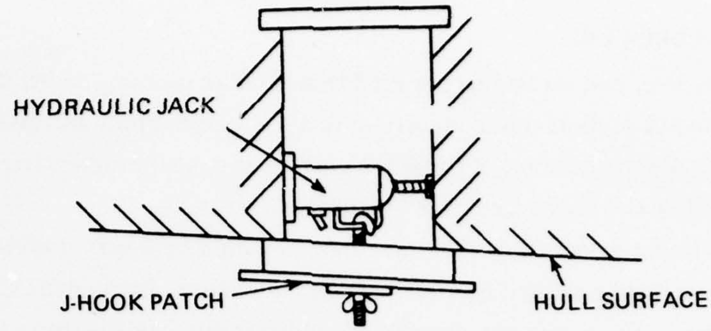

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Figure E–8. J–Bolt Patch Cofferdam[12.]

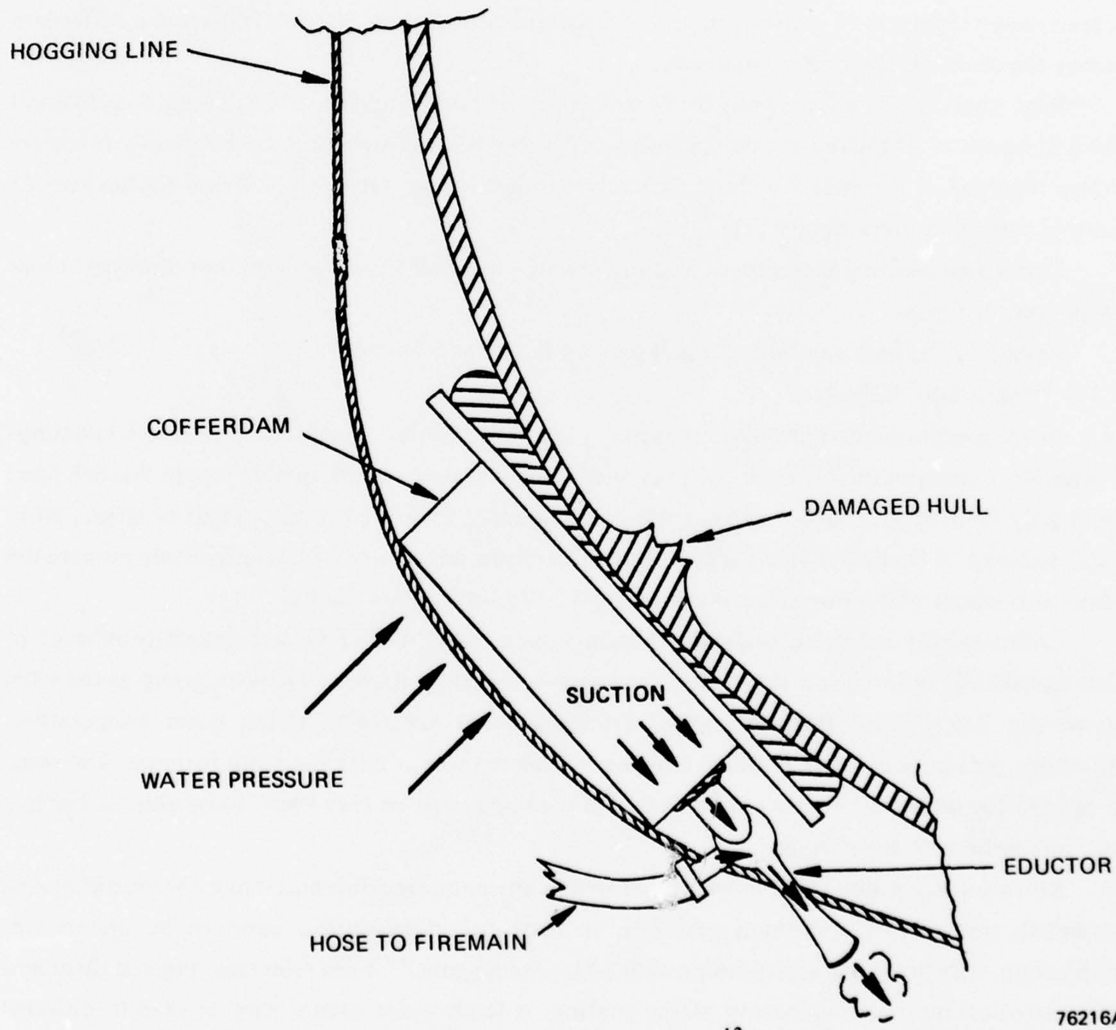

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Figure E–9. Suction Cofferdam[12.]

E.3.3.2 Sea Chests (Continued)

Wherever possible, bolt-on flanges are used to seal off an opening, rather than a patch. These can be equipped with one or more pipe connections to allow liquid supply and discharge functions to continue as required. A good example of this is the pipe hook-up to the radioactive discharge opening of a submarine to allow the discharge water to be saved.

A buoyancy lifting device to handle these flanges would be a very useful tool to develop.

No real development is needed for these smaller cofferdams, although production of standard sizes and distribution to the repair sites would save much in-the-field design and construction time.

E.3.3.3 Hull Plate And Bilge Keels

Moderate structural damage to the hull may be repaired using a manned cofferdam to create a locally dry area. Work may then proceed in a normal fashion the same as if in drydock. This technique has been used by industry to weld two halves of supertankers together, using a wrap-around cofferdam to cover the seam on the bottom and sides.

Bilge keels which are partially torn away from the hull should have the damaged section cut away and removed. Replacement can be scheduled at the next drydock due to the usually extensive welding required at the hull interface. Severely damaged bilge keels will demand drydocking or extensive cofferdamming in any case.

Cofferdam welding techniques, and underwater weld repairs in general, are discussed more fully in section E.3.5.

Repair to the hull paint system is discussed in the next section.

E.3.3.4 Paints and Adhesives

At the present time, underwater painting is in a rather undeveloped state. Underwater coatings are generally expensive and difficult to apply and result in a questionable quality repair. As such, they should only be used for touch-up and repair of small areas, or for temporary repair of larger, more critical sections. A first-class effort will require cofferdamming or drydock to effectively prepare the surface and recoat with conventional anticorrosive and antifouling paints.

Commercially available underwater paints such as STA-CRETE are generally inferior to paints specifically tailored to the task such as those supplied by Richard Drisko's group at the Civil Engineering Lab (CEL), Port Hueneme. Effects such as surface material, water temperature, antifouling, and anticorrosive features must be considered to optimize the paint formula. The same can be said for underwater epoxy adhesives. All coatings must be very "wet" to be able to displace water and adhere to the surface.

Surface preparation is the most critical step in any painting effort and is much more difficult to accomplish underwater. Common methods, in order of effectiveness, seem to be underwater sandblasting, wire brushing, and cleaning with 2-mm needle guns.[17] Even after cleaning, sediment and rapid corrosion may limit adhesion of the coating. A fresh-water stream may be used to dislodge sediment directly prior to the painting process.

E.3.3.4 Paints and Adhesives (Continued)

While most paints are epoxy compounds, polyester and coal tar epoxy formulations are also available. Polyester compounds are easiest to apply but take longer to cure and are softer and more easily damaged.

Antifouling additives in paints applied underwater are apparently of inferior effectiveness and lifespan compared with air-applied systems due to the difficulty of achieving a good leaching body using the epoxy compounds. Additives are sometimes used merely because they make the paint "wetter" and easier to apply.

There is a difference of opinion as to the best method of paint application underwater. A gloved hand, trowel, pressurized roller brush, and normal paint brush are all viable techniques. The best one for any application depends on individual preference and the characteristics of the formulation. A typical application rate is 12-20 ft^2/hr.

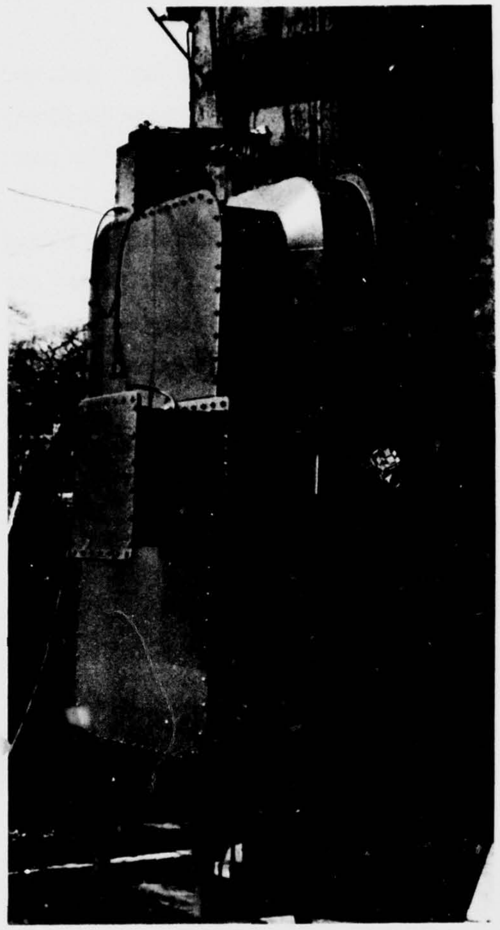
Splash-zone compounds (one is MIL-P-28579 (YD))are two-part epoxy formulations of high viscosity which are applied with a gloved hand or trowel to a cleaned surface. These "paints" slowly erode when underway to give a smooth surface. Splash-zone compounds average about $12.00 per gallon (as of 1976), which covers 7 1/2 ft^2 to a thickness of 0.185 inches for a material cost of $1.60 per ft^2. Application rate averages 6 ft^2 per hour.

The CEL-developed underwater brushable epoxy costs $24 a gallon, which covers 175 ft^2 to a thickness of 8 mils, resulting in a material cost of $0.14 per ft^2. Application rate may be as great as 35 ft^2 per hour.

The labor (diver) cost for either system will be the major cost item. Typical figures are $8 and $1.35 per square foot for splash-zone and brushable epoxy systems respectively exclusive of cleaning and preparation charges.

Much work needs to be done to develop more effective underwater paints and application methods. Current paints are intolerant to changes in water temperature and require great care in surface preparation even when thick coats are applied. In this regard, methods of surface preparation must be developed and rated as to their relative effectiveness. Application systems also must be improved. The injected roller system should be further developed. A system employed in the Soviet Union, whereby a soft rubber rotating disk is injected with paint which is subsequently rubbed or buffed onto the surface, displacing water in the process, has not been pursued in this country. Neither has a system developed in Japan by Inouye and Co. whereby a small cofferdam, moved by means of magnetic wheels, is located over the damaged area and is sealed and dewatered using pressurized air. Infrared heaters dry the surface, which is roller painted and dried again. This process may be repeated for multiple coats in one area or the unit may be moved to cover another section. Figure E-10 shows a prototype unit.

Colebrand Ltd. in Britain reportedly has developed a similar cofferdam type automatic underwater spray painting system. The unit is supported at the surface by two ballast tanks and is held



(1)	Body dimensions (L x W x D)	
	External	2.67m x 1.96m x 1.09m
	Weight	2t
(2)	Coating device	
	Forcing type roller coating machine	69ϕ x 225m
	Brushing speed	21.5m/min
	Driving motor	60~1,710rpm 0.4 KW (1/2PS)
	Reduction gear	1/30
	Chain — cross feed	JIS60 roller chain
	Chain — file feed	P=50 plate roller chain
(3)	Drying device	
	Super infrared rays heater	200V 1.5KW 15 pc's
	Illumination	1.11W/cm^2
	Applying distance	0.6m
(4)	Absorption device	
	The body of the coating machine is to be absorbed to the hull using electro magnet.	
	Absorption force of one piece	2.921 t
	Setting No.	14 pc's
	Total absorption force	40.896 t
(5)	Body's cross feeding device	
	Caterpillar type electro magnets are to be placed to the ship's bottom with air cylinder and the caterpillar is shifted by driving motor after the body is floated.	
	Shifting speed	5.76 m/min
	Motor	60~200W 18rpm (with reduction gear)
	Absorption force of caterpillar	60 kg
	No. equipped	3 sets

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Figure E–10. Underwater Painting Machine[26.]

E.3.3.4 Paints and Adhesives (Continued)

to the hull by means of suction pads. A "fishtail" nozzle is held a fixed distance from the hull by means of roller supports and can spray a 4-ft wide path using 1800 psi pressure. Details of system performance and effectiveness have been sketchy to this date.

Creating a locally dry condition by cofferdamming or ballasting and using conventional painting techniques will result in the highest quality paint repair.

Underwater adhesives require a similar developmental effort.

Experiments done at the Civil Engineering Lab (CEL) in San Diego, California, and at the Naval Coastal Systems Laboratory (NCSL) in Panama City, Florida, have shown that as with paints, surface preparation is critical for good adhesive bonding.[19.] Sandblasting and wire brushing were the two best methods discovered. However, field testing revealed bonding strengths only one-sixth to one-third those predicted by laboratory testing. Water temperature and amount of silt in the water appear to be critical factors affecting performance. Mixing the adhesive by hand in air produced much superior results to any kind of mixing done underwater, even when the mixture was protected from direct water contact by a plastic cartridge and mixed with a sealed plunger.

There appears to be no way of predicting performance for underwater applied adhesives. Consequently, they should not be relied upon for any kind of critical repair work.

As with painting, creation of a locally dry area by cofferdaming or ballasting will allow conventional adhesives to be used with no degradation of performance.

E.3.4 APPENDAGE MAINTENANCE

This section encompasses all devices which are not an integral part of the hull. Included are propellers, propeller shafting, rudders, and corrosion protection systems.

E.3.4.1 Propellers

Propeller grooming and minor repair can be done very effectively underwater. Cleaning using small diver-held rotary brushes and hand scrubbing or scraping is standard procedure and can significantly improve efficiency. In trials recently conducted by David W. Taylor Naval Ship Research and Development Center (DTNSRDC) on the USS HOLT, speed improved by 10 percent after cleaning the ship's moderately fouled propeller. Scraping is done using a knife, wooden or plastic scrapers, or scouring pads. Flat "butcher" wire rotary brushes clean to bare metal and leave a polished surface behind. There is a need to develop a small rotary brush of about 4-5 inches diameter specifically designed to clean small radius sections of propellers. This would be useful for sea chest cleaning as well. A wire cup brush of about 4 in. diameter, coupled to a pneumatic grinder, may be used for this purpose until a more specialized and less unwieldly tool is developed.

Propellers may be removed and replaced while the ship is waterborne using one of several techniques. The best of these use either the "Charleston gear" puller or the newer "Pilgrim Nut" method. Both use hydraulic pressure to provide the pulling force.

The Charleston gear, or hydraulic ram, system uses two cylinders, connected by a strongback and working against the tail shaft to pull the propeller free of the shaft (see Figure E-11). Each cylinder is rated at 200 tons. Submarine propellers normally break free at about 2700 psi hydraulic pressure, the equivalent of 80 tons pulling force. Pressures may be double this figure in isolated instances. All water-borne repair facilities should be equipped with this system as it is effective, safe, and applicable to almost all classes of ships. The design and procedure for installation and removal is detailed by NAVSHIPYDCHAS DWG 203-1842704. When free of the shaft, the propeller is maneuvered by means of a strongback or lifting eye and lifting crane.

The hydraulic nut, or "Pilgrim Nut" method (named after its British designer) utilizes a built-in hydraulic jack within the propeller boss nut itself. The nut is grooved to hold a rubber tire and loading ring. The rubber tire may be pressurized using hydraulic fluid to create a force on the loading ring which may be used either to unseat a propeller for removal, or to seat a new one in place. To unseat a propeller, the nut must be removed, reversed, and partially screwed back on the shaft to within an inch or so of the hub. The loading ring can then act on a special backing plate which is attached to the hub using withdrawal studs (see Figure E-12).

For propeller installation, the nut is put on in the normal manner and screwed so the loading ring is up against the hub. Applying hydraulic pressure forces the ring against the hub and seats the propeller on the shaft (see Figure E-13).

The "Pilgrim Nut" is a breakthrough in propeller removal techniques and should be incorporated in the design of all future ships. It is already being specified on some new ships, including Trident and 688 Class submarines, and on some new destroyers. Consideration should also be given to retrofitting some existing ships, perhaps as a part of overhaul procedures.

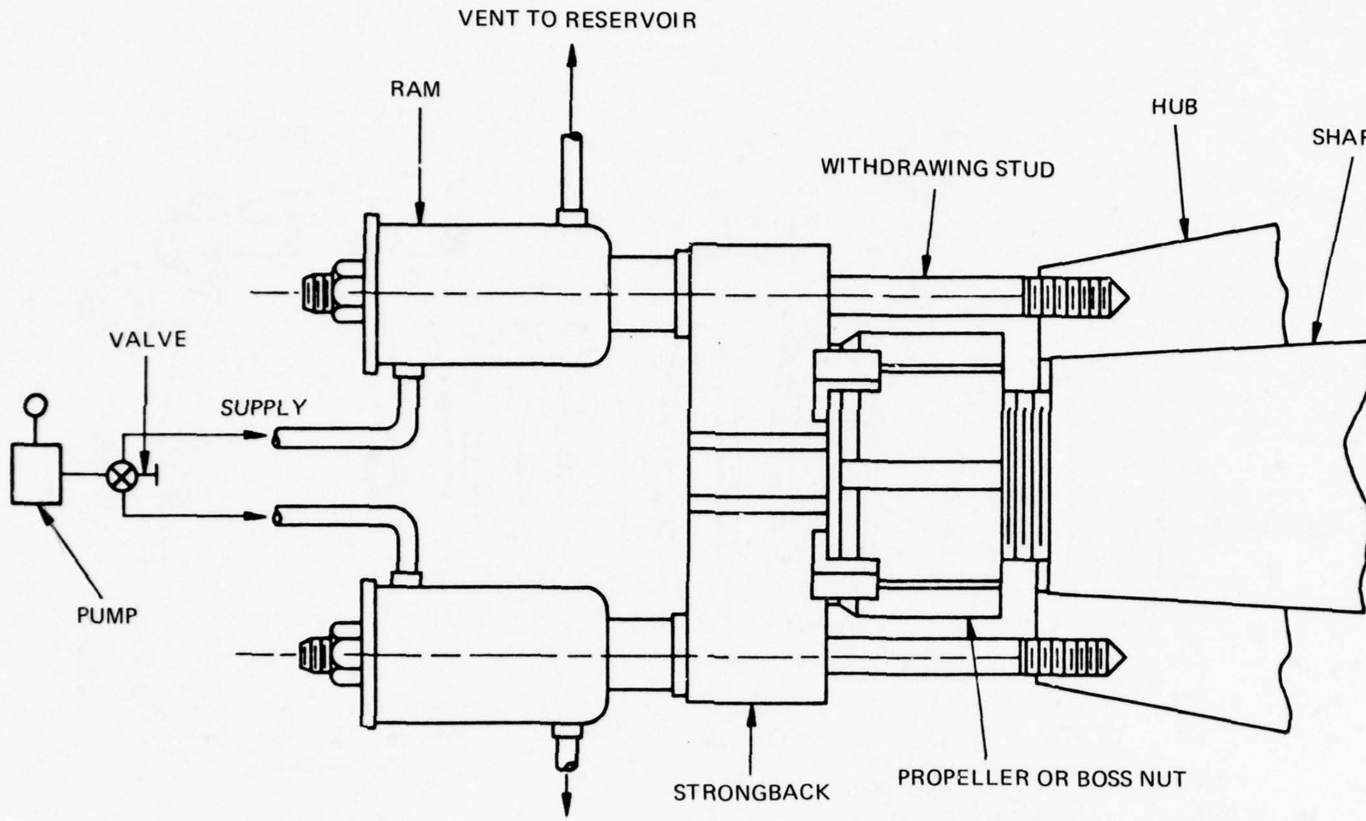

Figure E–11. "Charleston Gear" Hydraulic Ram Arrangement[12.]

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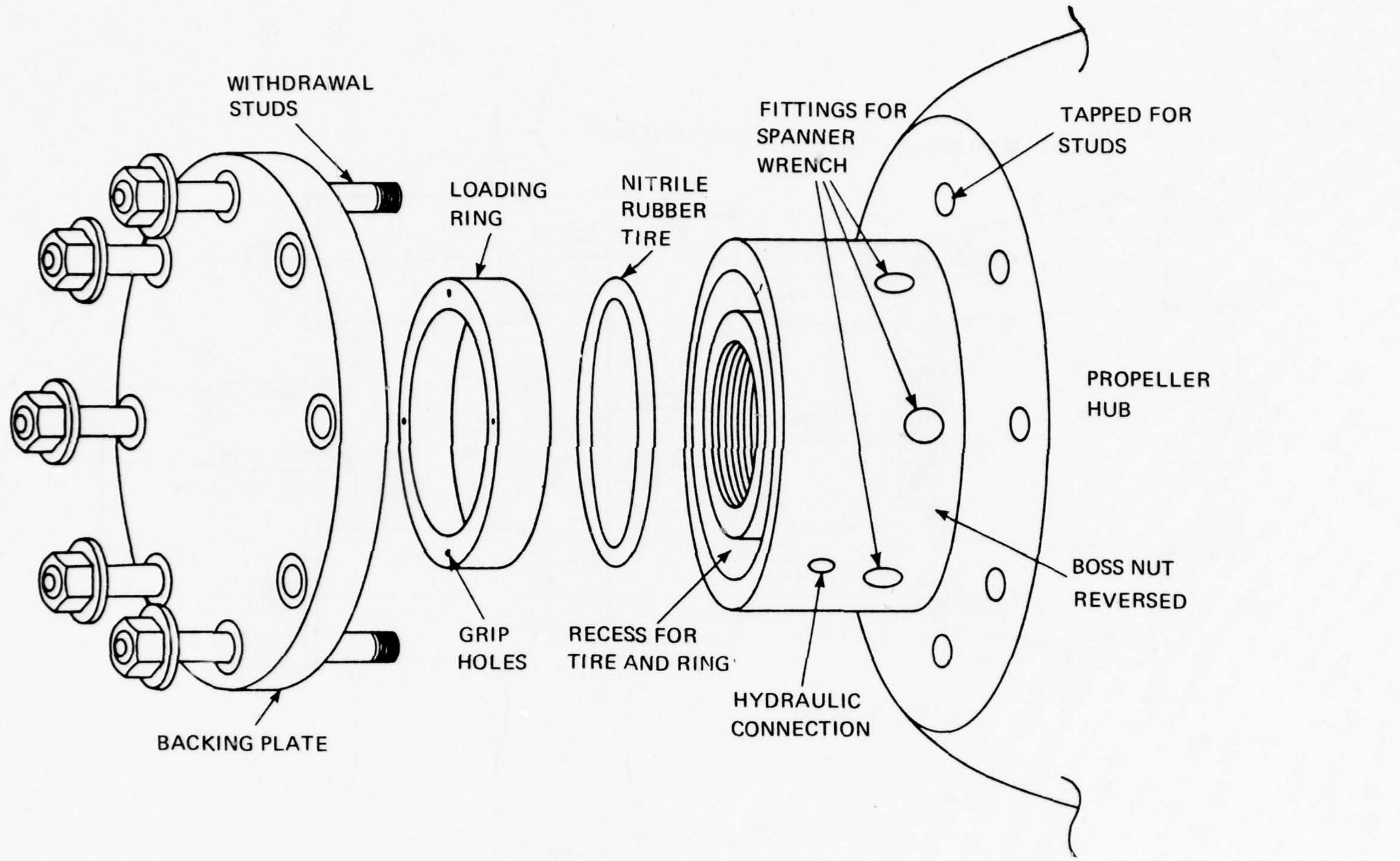

Figure E–12. Hydraulic "Pilgrim Nut" Assembled For Propeller Removal[12.]

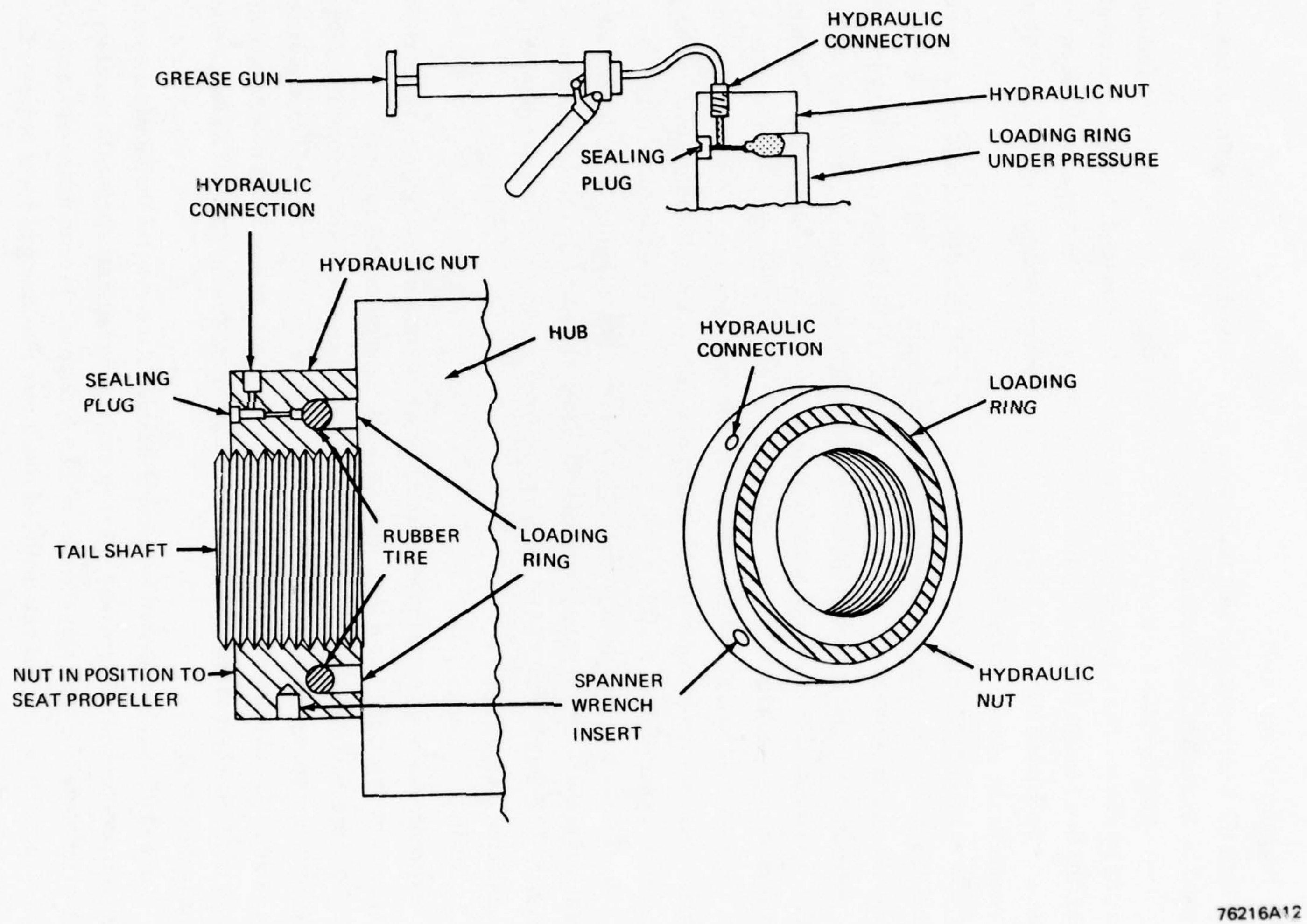

Figure E–13. Hydraulic Nut Setup For Propeller Installation[12.]

E.3.4.1 Propellers (Continued)

Both the Charleston gear and the "Pilgrim Nut" method have been quite successful and have been used in drydock as well as waterborne.

Two other methods for installing or removing propellers are the hydraulic jacking method developed by Electric Boat, and the primacord explosive force method. Neither are acceptable alternatives, the first because of the set up time of 24 to 36 hours and the bulkiness of the equipment involved, and the second because of safety considerations and possible damage to shaft seals and other components in the vicinity of the blast.

The edges of propeller blades are very sharp and present a cutting hazard to the working diver. On new or replacement blades these should have a protective covering which can be removed after work on the blades is finished. Small nicks and scratches in the blades can be filed or polished out.

Removal and replacement of dunce caps, boss nuts, and rope guards is little different from drydock operations and is usually accomplished without difficulty underwater. The removal job becomes more difficult in those instances where these items were orginally welded on. Dunce caps and new propellers should have all crevices and mating surfaces flushed free of seawater and pumped full of preserving fluid. Hydraulic connections are tapped on either side of sealing areas for this purpose. Blades on controllable pitch propellers may be removed and replaced individually.

Other navies do much more propeller repair underwater, including blade straightening, cutting out damaged sections, and welding in replacement pieces. The NCSL dive team recently straightened a blade on the USS RECOVERY (ARS-43) using the Hurst automotive rescue tool, however, the repair was considered temporary.

E.3.4.2 Shafts

Propeller shafts are not removed or replaced waterborne in the U.S. Navy, although there is no real reason why this cannot be done. Other navies apparently do this routinely[28].

There are two common methods employed. If the shaft is removed externally, pulling gear and support structure are rigged up and the shaft is partially removed. A "dummy" extension shaft is attached to the shaft end from inside the ship. The extension may be assembled in sections if the shaft is very long. The shaft is then completely removed, leaving the dummy shaft in its place to seal the hull and maintain alignment.

Some shafts may be removed from inside the ship. In this case, the shaft is withdrawn until only the tip protrudes beyond the stern tube. A hat-shaped sealing cap is attached to the stern tube, covering the end of the shaft. The shaft may then be completely removed. In certain cases this method may also be used if the shaft is removed externally, in which case the sealing cap will be inside the ship.

In all cases, installation is the reverse of these procedures.

Struts, fairwaters, and shaft seals often require inspection and repair. Struts may become cracked and require welding, in which case drydocking has usually been required. It may be possible to weld dry underwater by creating a cofferdam seal around the shaft.

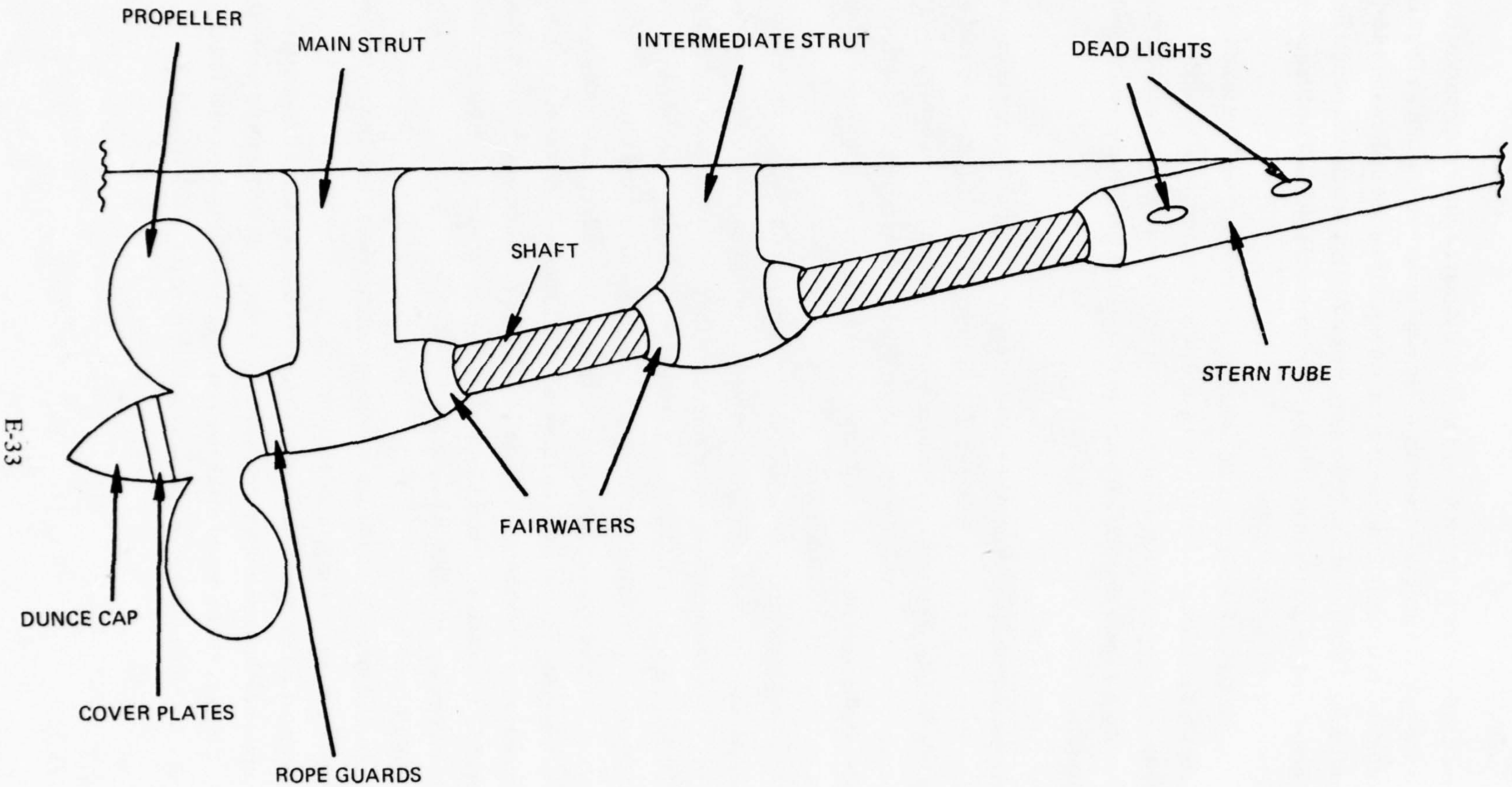

Figure E–14. Typical Drive Train Components[12.]

E.3.4.2 Shafts (Continued)

Shaft fairwaters are either bolted or welded in place and may be either stationary or rotate with the shaft. Welded units are not generally removed or replaced underwater, although there is no real reason why this could not be done. Bolted designs are much easier to handle underwater and should be a ship design requirement. They should also be designed with lifting line attachment points. Fairwaters are assembled in halves, and because of their weight (75 to 800 pounds each half) will require handling lines or lifting devices to aid in replacement.

Shaft bearing maintenance and repacking procedures are usually done from inside the ship. As part of this task, the shaft is sealed at the stern tube using divers to assure against through-hull leakage. This job is accomplished using a tapered collar pressed to fit between the stern tube and shaft, or by wrapping a rubber sheet around this area. Wooden plugs or small patches are used to seal cooling water ports in the tube.

E.3.4.3 Rudders

Rudder sag measurements to determine bearing wear on surface ships are accomplished routinely waterborne. Outer packings may be repacked using divers, allowing the inner packings to be repacked from inside the ship. This task may be done waterborne using less manpower and time than in drydock, primarily because no scaffolding is required. Rudders may be checked for flooding using soundings. Flooded rudders are blown out using high pressure air introduced through a fitting and expelled from a plug at the bottom of the rudder.

Replacement and structural repair of rudders has generally been restricted to drydock operations within the Navy; however, the expertise exists for performing these tasks while waterborne.

In one of the few cases of underwater rudder repair in the U.S. Navy, a crack in the rudder of the carrier USS ROOSEVELT was patched by Taylor Diving Co. The 2-3 inch wide by 2-1/2 ft long crack was cut out and repaired by bolting a plate over the area and sealing it with epoxy.

Again, other countries accomplish much more extensive rudder maintenance, repair, and replacement tasks routinely. Typical work includes lifting the rudder by means of a line run through the rudder trunk, allowing replacement of pintles, gudgeons, bushings, and bearings. Rudders are removed and replaced by means of winches located so they are capable of proper positioning. Wet welding is a common means of rudder repair in the USSR.

E.3.4.4 Corrosion Control

Corrosion control methods include the impressed current system, installed on most newer surface ships, and the more common zinc anode system.

Underwater work on the impressed current system has been limited to inspecting the reference cells and the condition of the tantalum anodes. So far, the capastic dielectric shield has been repaired only in drydock. Cofferdamming would make this task feasible while waterborne. The entire system should be shut down while divers are in the water to minimize the shock hazard.

E.3.4.4 Corrosion Control (Continued)

Bolted-on zinc anodes are routinely replaced underwater. Because of the great numbers involved, typically 80-800 per ship, this is one area where power tools are appreciated. Zincs which are welded on must be cut or ground away from their straps. Replacements are then either clamped or bolted to these original straps, a difficult, time-consuming job. Welded zincs should be eliminated from ship design wherever possible and whenever waterborne replacement is assumed.

E.3.5 WELDING AND CUTTING

In the following section, the types of underwater welding which are currently being used to a significant extent are surveyed. Underwater metal cutting is also discussed briefly. The application of this technology to underwater ship repair is then discussed.

E.3.5.1 Underwater Welding of Steel

It should be noted that much of the published literature on underwater welding is concerned with welding at great depth, i.e., several hundred feet. Accordingly, some of the conclusions and remarks in this literature need to be reinterpreted for the present objective where welding would be required only at shallow depths. For example: the effect of pressure on the arc characteristics and on chemical reactions is not a significant factor in the present instance. Likewise, some of the logistic problems in furnishing life support and materials to the welder-diver are much simpler in the present instance.

The main criteria used for evaluation of the various processes are: feasible weld quality, post-weld inspectability, qualitative assessment of cost, and equipment required.

E.3.5.1.1 Wet Welding

Broadly speaking, there are two levels of sophistication in wet-welding. The older/cruder technique is the "drag" technique and the newer more sophisticated technique is the Chicago Bridge and Iron (C.B.I.) multipass technique[1, 2] (with a more nearly normal type of arc). In both cases, the process is basically a stick-electrode (SMA) process. In the "drag" technique, use is made of the fact that the electrode has a heavy coating which burns off more slowly than the metal core. This results in a hollow electrode tip and also permits dragging the electrode over the work (the coating being nonconductive) so that the welder can work partly by feel. Unskilled welders may rely entirely on feel by maintaining the electrode in the weld groove. However, as the groove is filled up with successive passes, it is less well defined and following the groove becomes more difficult, so that the technique is most appropriate for single pass welds. In the C.B.I. technique, more reliance is apparently placed on the welder being able to see the arc and weld puddle. (It is unclear whether visibility is better than in the "drag" technique or whether it is simply a matter of superior welder skill). In any case, it is understood that a normal type of arc is maintained and that the electrode does not contact the work.

The work at Chicago Bridge and Iron may be taken as the frontier of achievement in wet-welding. They have made welds in submerged pipelines, offshore structures, and (USN) ship hulls. Welds have been made in depths to 166 feet and include overhead welds. Materials welded are structural steels, including the medium steel used for some USN surface ships. Strengths of weldments are generally equal to in-air welds although ductilities are typically 30 percent lower.

E.3.5.1.1 Wet Welding (Continued)

C.B.I. has a very proprietary attitude concerning details of their technique, but the important features of their technique appear to be:

- Personnel. Welding is performed by welders trained as divers (elsewhere it is usual to take divers and train them to weld). Constant practice is regarded as an important ingredient of success, to the extent that practice welds are made during periods of low commercial activity.
- Electrode Composition. Ferritic type electrodes (E 6013) are used for carbon equivalents (CE) up to 0.4 percent. Above this CE level, austenitic electrodes are used. The austenitic weld metal cannot be quenched to a brittle martensitic condition so that the post-weld cracking problem is much reduced. Another favorable aspect of austenitic weld metal is that it is not embrittled by hydrogen (for which it has a high solubility). Composition of the C.B.I. austenitic electrodes is not available.
- Electrode Protection. It is understood that proprietary coatings are applied to the electrodes to prevent contamination. Also, special handling techniques are used in transferring electrodes to the underwater welder.

The ability to make multipass welds (presumably with interpass inspection and cleaning) has been a considerable achievement of C.B.I.

Nondestructive inspection of the C.B.I. welds is performed by independent organizations. Magnaflux (Houston) has performed ultrasonic tests on C.B.I. welds. Underwater pipeline welds have been satisfactorily ultrasonically (UT) inspected to API 1107.

Oceaneering International is a more recent entrant into the wet-welding business and competes with C.B.I. They have similar capability to C.B.I., but they do not appear to have the specialized electrode developments of the latter.

Work is in progress at the Charleston Naval Shipyard to upgrade the "drag" technique and to obtain consistent underwater weld quality. In this work they try to put down as much metal as possible in the first pass (sizing the electrode to the groove) in order to eliminate the necessity for multiple passes. The "drag" technique is considered adequate for the emergency type repairs which are sometimes needed. Charleston uses divers for this work who have to be trained as welders.

A visibility problem sometimes arises in wet-welding below a large flat surface (e.g., a barge hull) due to accumulation of exhaust bubbles from the diver's helmet. In most cases, it is possible to overcome the problem by some simple procedure: for instance, by inducing water circulation in the area. Wet-welding requires a minimum of equipment and set-up time and is probably the lowest cost of the processes to be discussed (with the possible exception of underwater hull welding performed from inside the hull). On the other hand, the process does not produce top quality welds with respect to mechanical properties, and the welds performed on naval ships have generally been either emergency procedures or applied to areas of low criticality. Recently, wet-welding (using austenitic electrodes) was used to blank 63 openings in the underwater hull of the cruiser USS NEWPORT NEWS in

E.3.5.1.1 Wet Welding (Continued)

preparation for deactivation. This procedure eliminated a drydock operation. Hopefully, the hull plate in the wet-welded areas will require only grinding and minor weld-repair when the ship is eventually reactivated.

The procedure may not be suitable for a hydrogen-sensitive hull material such as HY-80 since a small amount of hydrogen may be introduced into the parent metal of the weld heat-affected zones where cracks might develop.

To some extent, the low quality of welds made in-the-wet can be compensated for by overdesign with respect to strength. However, the toughness required in shipyard welds for combatant hulls may be difficult to obtain in wet-welds. These toughness requirements are discussed in reference.[3]

E.3.5.1.2 Localized Dry Environment Welding

In this process, a local gas environment is maintained in the immediate vicinity of the weld so that the quenching severity is reduced. In its most rudimentary form (which was not exploited commercially) an SMA torch was used [4] and the gases generated from the electrode coating formed the protective atmosphere in the localized enclosure or shroud, which comprised a small volume in the vicinity of the torch and welder's hand. A gas supply was not required.

The latest evolution of this process is the HYDROWELD process developed by HydroTech Systems, Inc. Their enclosure or chamber (HYDROBOX) is of low-cost sheet metal and plexiglass construction and is fabricated anew for each application. The chamber is open at the bottom so that after placement, the water can be displaced from it by introducing gas at ambient pressure. Typically, the chamber dimensions are ample enough so that the welder/diver has most of his body in the gas environment. In some small applications, only the welder's arms and hands are in the gas environment (inserted from the open base of the chamber). HydroTech generally uses a GMA welding technique with the shielding gas providing the protective gas environment. Recently they have started to use a higher productivity technique: flux-cored wire with continuous wire feed. Commercial electrodes are used. Gas is introduced independently to maintain the gas environment.

A full range of power tools is used and provision is made for their handling and temporary storage in the dry environment. After weld-preping the joint area is dried by blasting with the shielding gas or by air from an air hose.

High quality welds are obtained which comply with API 1104 and ASME Section IX, with respect to both mechanical and NDT requirements.

HydroTech has found it necessary to use preheat (with electrical resistance heaters) in making repair welds on 1-1/2 inch wall pipe. They have made a repair weld to an offshore structure which simulated closely the geometry and overhead welding which would be involved in repair welding a ship hull.

The HYDROWELD process appears to have substantially overcome the quenching and hydrogen problems in underwater welding of structural steels. It remains to be seen whether it can produce quality welds in a quench-and-temper steel such as HY-80.

E.3.5.1.2 Localized Dry Environment Welding (Continued)

The application of HYDROWELD to hull repair appears straightforward in cases involving damage where the hull has not been penetrated and where the repair can be effected without a penetration (repairing shallow cracks perhaps). On the other hand, if the hull has been penetrated, or if plate must be replaced, its application becomes more complicated since free communication exists to atmosphere and the gas environment cannot be maintained. Schemes for overcoming this problem are discussed in a subsequent section.

E.3.5.1.3 Habitat Welding

In this method, a large chamber (open at the bottom) surrounds the structure (i.e., pipeline generally) to be welded as well as the welders. The gas environment in the chambers is at ambient depth pressure, as in HYDROWELD. Weld preparation equivalent to normal in-air technique can be effected and welder's visibility is normal. Weld quality equal to the best in-air technique is claimed. Nondestructive testing can be performed as in-air since there is no interference from the water environment.

Taylor Diving and Salvage, Inc. is the most important user of this technique[6]. In their technique, the humidity of the chamber atmosphere and the CO_2 level are controlled. Their welding technique is generally SMA with the gas-tungsten arc process (GTA) used for the root pass. They (Taylor) claim to have made hydrogen checks on weldments made in their habitats which show levels equal to, or better than, that of normal in-air welds. Their pipeline welds include portions which are made in the overhead position. They have applied preheat (to 200°C) to joints in some cases, using electrical resistance heating. When using preheat to the higher temperatures, they have found it necessary to shield the welder-diver against radiant heating.

It should be noted that the HYDROWELD process is basically similar to habitat welding if a large gas enclosure is used. Some of the distinctions between the two methods pertain only to pipeline work. For instance, the Taylor system is intended to do more than welding: the elaborate heavy-construction habitat also aligns and fixtures the pipes for welding.

E.3.5.1.4 Localized Cofferdam Technique

Using localized cofferdams as described in the Underwater Work Techniques Manual [12], normal dry welding and cutting on the hull may be performed from inside the hull. Good quality welds appear feasible by this method subject to the limitation of access to one side only. After completion of the weld, the cofferdam can be removed and an underwater paint applied to the area. It appears that the quality of the root pass would be suspect because of the high humidity in the cofferdam and because of the less-than-optimum exterior weld preparation which is feasible. To some extent, the problem may be minimized by grinding off the root pass (in-the-wet) prior to applying the coating. The technique has been used so far only for temporary hull repairs. It has also been used to permit replacement of welded-on waster-sleeves inside large sea chests. This is a low cost technique (perhaps even lower than wet-welding).

E.3.5.1.5 Welding in Large Cofferdams With Waterline Access

Japanese shipyards have used this method in construction of very large tankers: the vessel is constructed in two halves at different locations. Each half is launched separately and they are floated together and mechanically fixtured. A tunnel-like cofferdam is constructed to span the joint (waterline to waterline) in which a prime quality weld is made after dewatering the cofferdam. Under these conditions, the welding process is only a slight extension of normal shipyard welding and the welder does not need to be a diver. Atmospheric pressure in the cofferdam is one atmosphere so that arc behavior and weld chemistry are entirely normal.

E.3.5.2 Underwater Welding of Nonferrous Materials

No work has been performed on underwater welding of nonferrous materials. Two types of problems are likely to arise which might be solved by underwater welding:

- Damage to nickel-aluminum bronze propellers
- Hull damage to aluminum alloy hull ships

In both cases, there are reasons for not concentrating on underwater welding as the solution. Propellers can be changed in the water if necessary. So far as aluminum alloy hulls are concerned, the small numbers involved represent a small part of the overall problem so that R&D efforts in this area would have negligible pay-off compared with similar efforts applied to steel hulls.

E.3.5.3 Metallurgical Aspects — Underwater Welding

Two of the special problems of underwater welding, hydrogen effects and quenching, are considered below with respect to their impact on the Navy's requirements.

E.3.5.3.1 Hydrogen Effects

Evaluation of underwater welds to date has involved limited types of mechanical tests compared with the testing required to qualify in-air weld procedures. Emphasis has been on producing defect-free welds with strengths equal to that in welds made in air. Impact properties are sometimes determined.

Many of the potential problems in underwater welds concern hydrogen effects which induce several characteristic mechanical behaviors in steel and which can result in degrading mechanisms which may easily escape detection in the small number of tests which are usually required for welds produced in dry environments. As an example: the embrittling effect of hydrogen in steel is typically a maximum at a very low strain-rate ("slow strain-rate embrittlement") and often will not be apparent in the normal strain-rate tensile test and impact test (which is designed to detect conventional brittle-fracture). In dealing with applications where hydrogen pick-up is a possibility, it is therefore necessary to go beyond the questions usually resolved by the routine mechanical tests.

Welding performed below the waterline, even when performed in a habitat, has a greater probability of hydrogen contamination than is the case for normal dry-land welding (because of the less than ideal working conditions and the latent susceptibility to high humidity). It is desirable, therefore, that process and performance specifications for quality welds made below the waterline

E.3.5.3.1 Hydrogen Effects (Continued)

(whether made "in-the-wet" or "in-the-dry") contain tests to establish freedom from hydrogen contamination. Two types of tests are appropriate:

- A restraint cracking test (several standard types such as the CTS and Circular Patch Tests have been developed) or an underbead cracking test. This type of test guards against the possibility of post-weld cracking (i.e., in a period of days or weeks after completion of the weld).
- Tensile tests at very slow strain rates (say, 0.0005 in/in/minute). This would give information on embrittlement under conditions of slow plastic flow (such plastic flow as might occur at stress-raisers during service).

In order to make these test requirements more specific it is recommended that the expertise of the Naval Research Laboratories be called upon. This would consist of a detailed study of mechanical properties of underwater welds currently of interest to the Navy and would be a continuing assignment wherein new processes or new materials would also be examined.

Another aspect of the hydrogen problem is that to some extent hydrogen will diffuse out of hydrogen-contaminated weldments after completion of the weld so that a post-weld holding period can be beneficial. If the weld temperature can be maintained slightly above ambient the outward diffusion will be more rapid. Welds which are made underwater in unfavorable conditions (with respect to hydrogen) would benefit from a post-weld holding period to remove hydrogen. In the case of cofferdam welds, this might involve maintenance of the cofferdam in place for a period of hours or days, preferably with local heat applied to the weld area.

E.3.5.3.2 Quenching of Welded Steels

In underwater welding, the contact of the metal with ambient water causes rapid cooling of the weld region and a tendency for formation of brittle untempered martensite. The severity of the problem depends on the carbon equivalent of the weld metal and of the base metal. The cooling is severe for wet-welding, resulting in limitations on the types of steel which can be wet-welded with ferritic type of electrodes without cracking problems. The problem is much less severe with habitat welds where the cooling rate will depend mainly on the habitat dimensions (more exactly, the distance from the weld to the nearest water as measured through the metal) and the water temperature. In welding steels such as HY-80, which require a preheat temperature substantially above ambient, these considerations may dictate the dimensions or geometric details of the habitat or cofferdam. The minimum weld-to-water distance would readily be calculated using heat-transfer theory (and given the heater-power and water temperature).

Some tests have been made[8.] in an attempt to make laboratory wet-welds in HY-80 steel using austenitic (E310) electrodes to eliminate the quenching problem. The scope of the tests was limited. The results indicated that the technique may offer a method for making a temporary repair in an HY-80 steel hull. While the possibility should not be excluded, it should be borne in mind that many types of tests should be used in the qualification procedure since some hydrogen effects may be present in the heat-affected zone.

E.3.5.3.2 Quenching of Welded Steels (Continued)

A particular potential problem is pointed out with respect to the use of austenitic weld metals (although information specific to the joining of HY-80 has not been obtained): a very narrow brittle zone is likely to be present at the edge of the fusion zone where the parent metal has been heated into the austenitizing range. Very fine cracking in this region, detectable only by metallography, is a persistent problem in clad-welds in the nuclear industry[9].

E.3.5.4 Specification Activity

In any future work, the recent issuance of a specification on underwater welding should be noted: MIL-STD-1692 (YD), "Underwater Welding Requirements for Naval Facilities", 2/10/76. This document provides general guidance on development and qualification of underwater welding process with emphasis on wet-welding.

A subcommittee on underwater welding has been set up by the American Welding Society and is in the process of writing a general specification for underwater welding.

E.3.5.5 Current R&D Activity in Underwater Welding and Related Areas

R&D work is underway at two locations which is likely to produce results relevant to underwater welding in ship maintenance:

1. NAVFAC has recently initiated several programs in the area of underwater welding and inspection. The objectives are broad, encompassing both deep and shallow welding on offshore structures as well as for ships. Much of the work will, however, be directly relevant to the present task. Major items of this work are:
   - Evaluation of commercially-available electrodes (waterproofed electrodes for wet welding, electrodes and wire for habitat welding)
   - Electrode development for wet welding
   - Evaluation of training needs and equipment for underwater welding
   - Development and optimization of underwater inspection tools
2. Underwater welding research is in progress at the Welding Institute (U.K.). The emphasis in this work is on metallurgical evaluation of the processes, electrode development and arc-behavior. The results are, and will be, in the public domain. Information on the hydrogen problem such as already has been published[10] is likely to be relevant to the present task.

R&D is also being pursued at the following organizations, but is concerned mainly with the problems of welding at great depth and is not considered to be especially relevant to the current task.

- Massachusetts Institute of Technology (MIT)
- Government Research Institution (Japan)
- Batelle Memorial Institute (Geneva, Switzerland)
- Mitsubishi Heavy Industries, Ltd. (Japan)

E.3.5.6 Underwater Cutting

Available technology and equipment appears to be adequate for torch-cutting of ferrous materials. On the other hand in the torch-cutting of nonferrous metals there is the problem that the existing techniques are undesirably slow for many applications. This limitation was illustrated by a recent incident involving the USS NEW ORLEANS (LPH-11). One blade of the 4-bladed propeller was lost while underway so that the ship had to reduce speed and head for Pearl Harbor Naval Shipyard. Since a replacement propeller was not available at Pearl Harbor it was decided to remove the opposite blade so that the ship could continue its transit to San Diego. Underwater cutting was first tried but was found to be excessively slow: removal of the blade would have taken 4-5 days. The underwater cutting approach was, therefore, abandoned and the propeller was removed with the ship waterborne and the cutting performed in air. Availability of a rapid underwater cutting method for bronze would have saved both considerable time and expense. However, it is doubtful that this type of requirement would occur with such frequency that special R&D activity should be initiated (and since improved methods for underwater propeller changes will become increasingly available as discussed in section E.3.4.1). Requirements for underwater cutting of other bronze ship components are likely to be even less frequent.

E.3.5.7 Application of Present Underwater Welding Technology to Ship Repair

In order to cover all types of welding repair which can arise, it would be advisable to have two or three techniques available for use. Important factors in selection of an approach for individual situations are: the material to be welded, weld quality required, location on the ship, type of ship (and its construction), and the available techniques. (For the purposes of this section, "welding" will include the post-weld procedures such as grinding and painting, since it is the total repair which is of interest).

For steel-hulled ships, the grades of steel involved will be Medium Steel, HTS Steel, HY-80, and HY-100. Difficulty of producing good welds increases in the above order, HY-100 being most difficult. The aluminum alloys used in some patrol craft are 5456 and 5086 alloys.

With respect to weld quality, the following three levels span the range and would cover most of the situations which will arise:

- Shipyard Quality Weld. Generally requires weld access from both sides. These would be welds equal to those made in initial construction, including full NDT inspection and painting. An example might be a hull weld in a combatant vessel which will not be drydocked for 2-3 years.
- Interim Weld. High quality welds which might be equivalent to a shipyard weld but made under less ideal conditions so that some of the shipyard specification requirements cannot be met. These would have to be made under conditions such that there would be a high expectation that hydrogen and embrittlement problems could be avoided. An example might be a hull repair in an active ship (other than a submarine) which is scheduled to be drydocked within a few months and which is constructed of Medium or HTS Steel. Generally, this would be a nonstandard procedure requiring authorization on a case-by-case basis.

E.3.5.7 Application of Present Underwater Welding Technology to Ship Repair (Continued)

- Low Criticality Weld. Welds where some sacrifice in quality can be tolerated such as components outside of the pressure boundary. Examples would be: repairs to rope guards, attachment of waster sleeves, temporary frameworks used in sonar dome repairs. Also included would be some of the hull welding done in preparation for deactivation of a ship (where a sea-going hull weld is not needed).

The largest gains (towards the goal of elimination of drydocking) will be made if shipyard quality welds can be made because, (a) making lower quality welds, as is often done in emergencies, tends only to postpone the drydock requirement instead of eliminating it; and (b) all situations would be covered (whereas progress toward making lower quality welds is only applicable to a limited number of situations). The following approaches for pursuing the objective of shipyard quality welds are identified:

a) The long-term optimum solution would depend on the use of large cofferdams open to the atmosphere above the waterline. The repair procedures would then be the same as in a drydock except for some logistic problems. Cofferdam development for welding and other types of work is discussed in section E.3.2.4 of this report. Such cofferdams would be comparatively easy to develop for the near vertical sides of a ship, but would be a more considerable development for reaching a flat bottom.

b) Another solution, probably within the capability of present technology, would involve the use of a habitat which mates to the hull in a localized area surrounding the repair. This solution subdivides into two cases: first, the case where the hull is penetrated at some stage of the repair (as when hull plate is being replaced), and secondly, the case where the hull is not penetrated (as in repair of a superficial defect). If the hull has to be penetrated, the habitat repair methods in which the habitat is open to the water at the bottom would require some special procedures for maintenance of the gas environment at ambient water pressure. In many cases involving surface ships, this could be achieved by extending the pressurization into the double-bottom space (see Figure E-15) while welding is performed from outside the hull (i.e., within the habitat). After completion of this portion of the weld, pressurization within the double-bottom could be removed and welding performed from inside the hull.

   An alternative method for preventing loss of the gas habitat would be to mate a totally enclosed hard habitat to the hull which is entered through an entry-and-exit lock and in which a one-atmosphere pressure is maintained. This solution would be more versatile (and more costly) than the previous concept since it would be applicable to submarines (which do not have a double-bottom) and to portions of surface ships to which the double-bottom does not extend.

In the case of repairs which do not involve hull penetrations such as clad welding used for restoring corrosion damage, these difficulties do not arise.

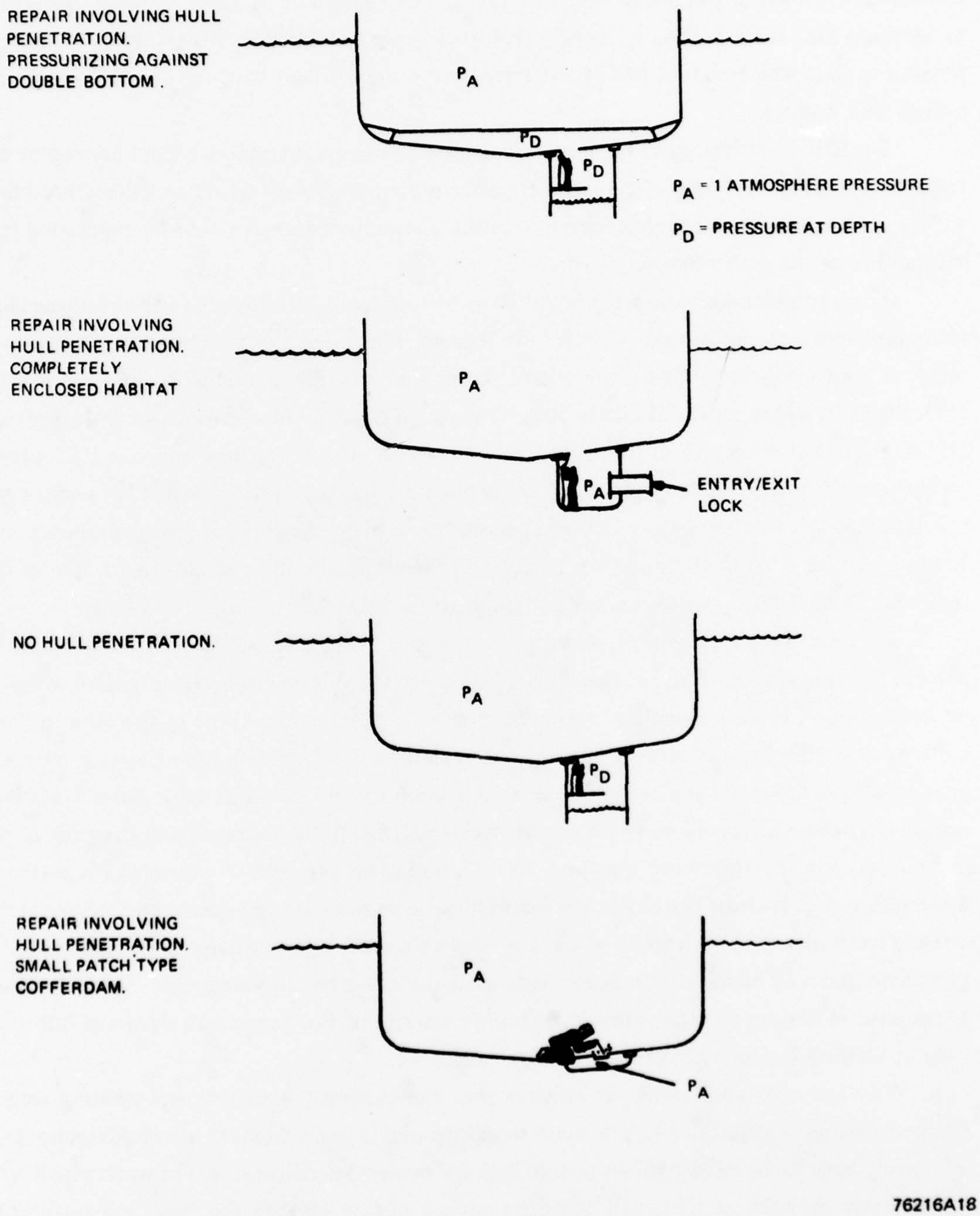

Figure E–15. Methods For Effecting Hull Welds "In–The–Dry"
(P_A = 1 Atmos. P_D = Depth Pressure)

E.3.5.7 Application of Present Underwater Welding Technology to Ship Repair (Continued)

After making a habitat weld, the post-weld painting would be accomplished with the CEL Epoxy Underwater Paint which could be applied dry and cured either dry or "in-the-wet". Conceptually, it seems likely that shipyard quality welds might be obtained by these habitat methods in Medium and HTS Steels. To obtain this quality weld in an HY-80 steel hull is a more remote possibility (but which should not be excluded) given the difficult working conditions which would prevail in a habitat.

The first step in establishing the capability to make shipyard quality welds underwater would be to place a contract with one of the commercial diving organizations which are experienced in habitat welding. Following a satisfactory demonstration a standby contract could be negotiated to ensure availability of the skill when required.

The interim quality hull weld might be most appropriately obtained by the localized cofferdam technique with welding from inside the hull. It seems likely that this technique (described in general terms in the Underwater Work Techniques Manual)[12] could give good quality joints in Medium and HTS Steels. It will be more difficult to obtain consistent good quality welds in (the hydrogen-sensitive) HY-80 and HY-100 because of root-side humidity and because of less than optimum joint preparation on the outer (root) side. However, these are problems which can probably be kept under control by special practices. For instance, by using appropriate weld geometry, root-pass procedures, and post-welding grinding (from the outside) it may be possible to obtain a quality weld, free of defective material. Dehumidification of the cofferdam space is also likely to improve quality.

In the specific case of replacing a section of hull plate, it would be possible to locate the new plate in position with backup bars attached (see Figure E-16). The localized cofferdam would have to be deep enough to permit maneuvering the plate into position (this type is known as a "high-hat" cofferdam at Charleston Naval Shipyard). After completion of welding the back-up bars would be ground off. A complete repair would include application of an underwater paint. This technique appears to have more promise, so far as return on the R&D dollar is concerned, than any of the other techniques, for the following reasons: (a) it should be possible to substantially overcome the hydrogen and quenching problems, (b) the welding does not have to be done by a diver, (c) the Navy already has experience with some of the key hardware and (d) low cost. With sufficient development this technique may be capable of achieving welds equivalent to shipyard welds. The technique is only applicable, of course, to repairs involving hull penetrations. For superficial repairs of hull exterior, a habitat method is required for high quality work.

For low-criticality welds, it appears that the currently available wet-welding technique is adequate for most applications. The main steps required in order to make use of this technology more effectively have to do with establishment of detailed process specifications. The work which NAVFAC has recently initiated at CEL will be an important step in making the Navy self-sufficient in this technology.

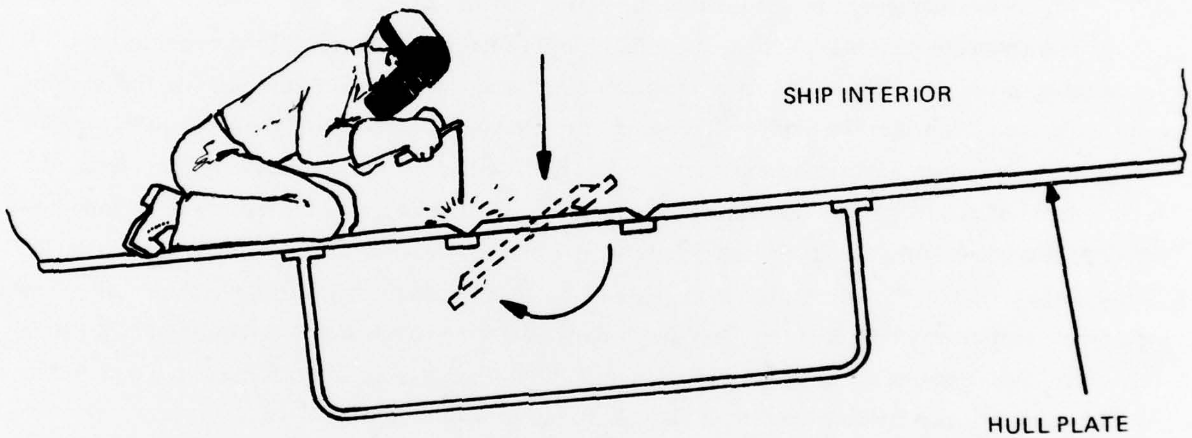

Figure E–16. Replacing Hull Plate By Working From Inside Hull. New Plate With Back-up Bars Attached Has Been Maneuvered Into Position.

E.3.5.7 Application of Present Underwater Welding Technology to Ship Repair (Continued)

With respect to the NDT aspects of underwater welding, it will be apparent from the discussion in section E.3.6 that most of the nondestructive testing methods used in shipyards can be used underwater and are already state-of-the-art. Technique and equipment have been developed and commercial organizations specializing in their application are in existence. The main questions which arise for Navy applications are concerned with such questions as:

- The extent to which existing NDT specifications are applicable. Can existing specifications be used with minor modification, or are new specifications required?
- Comprehensive guidance, perhaps in the form of a manual, is required for underwater NDT. Factors which influence selection of an underwater method will differ from those normally applicable. Selection of a method will, of course, depend on whether "in-the-wet" or "in-the-dry" testing is involved. In the case of some habitat and cofferdam work, the techniques might be identical with normal "in-air" practice.

The above discussion is predicated on the assumption that it is desirable to have a solution to all foreseeable problems. While this is a desirable goal, the decisions on funding for the various approaches must consider the likely frequency of various types of damage and the consequent types of repair. Our inquiries have indicated that serious hull damage (such as would require repair by replacement of a hull plate) is a very rare occurrence. On the other hand, repairs to various hull appendages (where some sacrifice in weld quality can often be tolerated) are frequently necessary. This is not to say that hull plate replacement should be regarded as a negligible problem; the very occasional instances where it is required may involve extreme urgency and a requirement for high reliability. For instance, a possible scenario might involve a large aircraft carrier based in the Mediterranean which cannot operate effectively because of hull damage.

E.3.5.8 Personnel Considerations in Underwater Welding

To carry out these repair programs will require an expansion in certain types of personnel and in some cases the development of new skills. The chief implications with respect to personnel are:

1. All proposed methods involve large amounts of diver work so that a larger pool of divers would be required.
2. Underwater wet-welding and habitat welding depend on individuals who possess a combination of skills and therefore these techniques present difficult training and personnel selection problems. These methods would also require underwater pay differentials.
3. Repairing of hulls and underwater appendages in large waterline-access cofferdams or by performing welds entirely from within the hull does not require welder/divers. Divers would be used to install the cofferdams but welding would be performed by welders (who require no diving skills). Training and personnel selection problems would be simplified compared with the other procedures. These considerations add support to the emphasis on large cofferdam development which is stressed elsewhere in this report. They also favor the development of the localized cofferdam technique for hull repair where welding is performed from inside the hull.

E.3.6 INSPECTION

Inspection tasks currently account for 47 percent of all ship husbandry related dives.[16] It is required to some degree before initiating any repair function, and is usually required after completion of the work to evaluate the success of the repair.

Inspections range the gauntlet from large area coverages required for fouling or paint condition monitoring to microscopic flaw detection required for weld repairs.

Other simple inspection tasks required include zinc anode evaluation, rudder sag and bearing clearance measurements, and damage assessment to plates or seams. Measurement techniques may be the same as in drydock, including the use of feeler gauges and ordinary tape measures.

Few guidelines exist for the underwater inspection task. A comprehensive document is needed to define underwater inspection techniques and acceptable standards, at least for the purpose of educating the working personnel. Commercially available test and inspection equipment should be evaluated and rated as to its effectiveness for Navy use.

E.3.6.1 Visual

The vast majority of hull inspections are carried out either visually or photographically. Visual inspections rely on the diver's interpretation, who may or may not be qualified to judge. Voice communication to appropriate people on the surface is very helpful in this case, and may be provided with several diving masks now in use.

The underwater damage assessment television systems, UDATS, has already gained wide acceptance with at least 35 units operational throughout the fleet. A permanent taped audio-visual record of the inspection process can be recorded. A certification agency representative or other qualified individual can view the site on screen and communicate with the diver as the inspection progresses. Clarity on screen is often better than the diver's eyesight, although poor visibility severely limits this system. In areas of extreme turbidity, such as Norfolk, a crack has to be at least 1/4-inch wide to be detected by UDATS. Nonetheless, it has proven to be very useful for inspection of specific detail areas or to provide comparative records over time of fouling and paint deterioration.

Black and white is the only system in Navy use although color and low light level units are becoming available. Head-mounted systems such as that developed by Hydroproducts (Figure E-17) promise to replace UDATS as the primary video inspection device, although they cannot reach into tight areas as well as the hand-held version. Head-mounting will free the diver's hands for work functions. Hydroproducts, Subsea, and General Aquadyne are all in the underwater T.V. market. EDO Western reportedly has a high resolution T.V. which can produce hard copy photos.

It should be noted that pointing the UDATS camera into the sun will destroy the lens. Also, if the light is turned on above water and becomes hot, it will break when submerged. In waters of poor visibility, better resolution is obtained by using a freshwater-filled extension lens.

Remote units, including some tenders, have difficulty meeting the 115 or 220 volts and 1/2 kW required by UDATS. Costs cover the range from $10,000 to over $30,000 depending on the system desired.

Figure E–17. Head Mounted TV Inspection System [32.]

E.3.6.1 Visual (Continued)

Color photographs have been found useful in documenting paint deterioration, plate corrosion, and fouling conditions. Photographs taken inside submarine ballast tanks are used as a prime source of this type of information. Stereo photography would allow size and depth to be recorded as well, although the technique is not now in use.

E.3.6.2 Remote Vehicle

Remote inspection systems are not in use within the Navy, although several are used commercially including the Hydroproducts free swimmer and the SCAN wheel-driven hull inspection unit. (Figures E-18 and E-19). Scan is held to the ship by means of positive buoyancy, and thus can only work on relatively flat areas of the ship's bottom. As such, it would be very limited for Navy use. In specialized instances, including inspection of very large ships such as aircraft carriers, remote devices may be a useful tool. A navigation system would have to be developed for any area coverage work. A method of adhering to the hull, such as the suction concept used by SCAMP (Appendix D), is also required to maintain inspection standoff distance (for T.V., radiography, and ultrasonic testing (UT)) and minimize effects of current.

In water inspection using SCAN has been approved by Lloyd's Register and the American Bureau of Shipping[35]. It is claimed that this system can inspect the bottom of a VLCC at the rate of 63,000 ft^2 per hour.

E.3.6.3 Nondestructive Testing Underwater

In order to be able to perform post-weld inspections on welds which may have been made underwater as well as routine inspections, a comprehensive nondestructive testing capability for use underwater is required.

The present capabilities of the various NDT techniques for use underwater are described below.

E.3.6.3.1 Radiography (RT)

This technique has the desirable features that it gives a permanent record and that it is insensitive to variations in microstructure such as inevitably occur at welds (in contrast to the ultrasonic technique.) Gamma radiography is used extensively in underwater work. (The cumbersome source and power supply required for X-ray radiography preclude its use in underwater applications). A powerful factor which has a strong influence on radiographic test technique (RT) employed in underwater work is the high absorption of the test radiation in water (compared to air). Thus, for example, in the offshore industry, radiography tends to be used for inspection of habitat welds where the in-air technique can be duplicated. In a current development, at least one company (Offshore Inspection, Ltd., Baton Rouge, LA.) is promoting in-the-water radiography using a technique for local exclusion of water from the source/film region (with air-filled rubber bags, it is believed). This development will offer a logical RT method for welds made in-the-wet. Most pertinent to this study: locations in submerged hulls are occasionally successfully radiographed at the Charleston Naval Shipyard. Technique is to locate the gamma source inside the hull and to replace the film against the hull exterior (by divers).

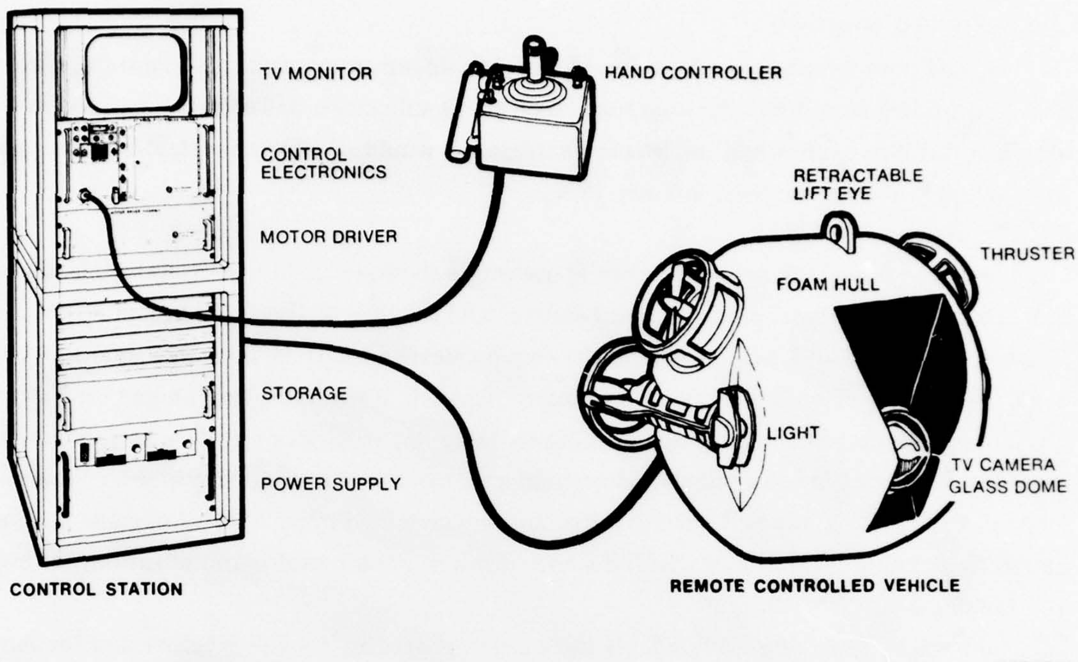

Figure E–18. RCV–125 Hydro Products Remote Controlled Vehicle System[32.]

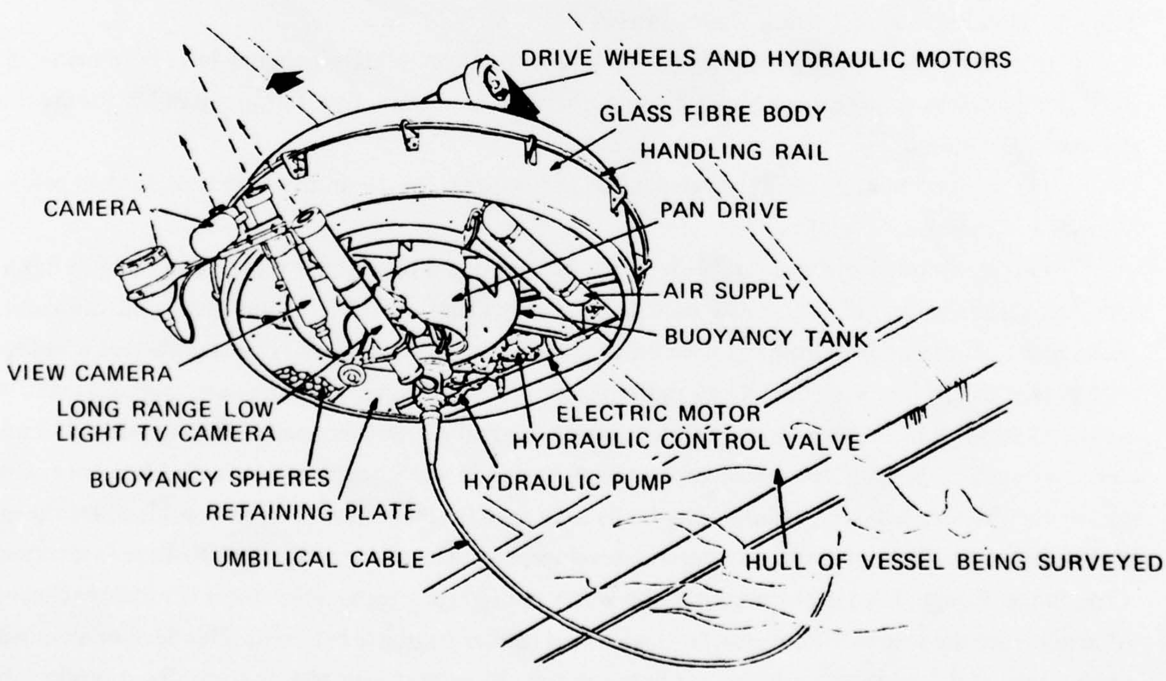

Figure E–19. "Scan" Remote Controlled Inspection Vehicle[33.]

E.3.6.3.1 Radiography (RT) (Continued)

Hull paint does not have to be removed. Careful lay-up of the film against the hull surface is required to eliminate trapped water. It appears therefore, that a radiographic technique is available for performing many of the inspection tasks required in underwater hull maintenance. On the other hand, it should be noted that radiography is sometimes ineffective for detection of very tight cracks so that complementary methods will be needed to cover all situations.

E.3.6.3.2 Ultrasonic Testing (UT)

This technique is used extensively both for defect examination and thickness measurement in underwater work, including "in-the-wet" testing. Theoretically, it can be used in water just as well as in air. It has the disadvantage that a permanent record is not obtained, so reported "indications" may be dependent upon individual operator interpretation to some extent. On the positive side, UT is good for detecting tight cracks which may not be found by radiography. The technique, as usually practiced for underwater work, comprises a diver in voice communication with the surface who manipulates the transducer, and an inspector on the surface who monitors the oscilloscope and tracks the transducer from the divers' comments. The close coordination of hand and eye which is an important feature of UT testing in air cannot be obtained by this method and some accuracy may be sacrificed on this account. The technique can be elaborated by having a second diver with a TV camera focused on the transducer track: the inspector then monitors a TV screen as well as the oscilloscope. In another mode, the TV record is taped for subsequent examination by the inspector. The recent development of helmet-mounted TV camera would permit a single diver to scan with the TV camera while moving the transducer.

For thickness measurement, at least one company (Detek Inc., Camp Springs, Md.) supplies an ultrasonic unit with digital readout for underwater use.

Ultrasonic inspection requires that the surfaces in the area to be inspected be reasonably good (perhaps 250 rms or better, provided the surface is not wavy). This requirement has two important implications for the present task: (a) in order to inspect underwater welds they would have to be ground smooth and, (b) a badly corroded hull might not be inspectable. The UT method does not require paint removal provided the paint is tightly adherent.

E.3.6.3.3 Eddy – Current Testing

This technique can be used for surface-connected cracks. It can also be used in a composition-sensitive mode for alloy identification. A permanent test record can be obtained (on tape). It is currently under development in the Navy for periodic surveillance inspections of hull welds and for detecting dealloying in certain bronze components. The method does not require paint removal. One company (Detek) is about to market a unit for underwater NDT inspection.[34] Surface finish must be good for the technique to be effective: generally the finish would have to be at the same order as that required for UT or somewhat better. On the other hand a greater degree of surface waviness can generally be tolerated.

The technique is effective in detecting tight surface-connected cracks such as hydrogen cracks which become an increasing concern as higher strength steels are introduced for hull construction.

E.3.6.3.4 Magnetic Particle Testing (MT)

According to verbal reports and advertising literature, this technique has been used underwater by the offshore industry. The procedures used have been adaptations of the standard in-air techniques and using the same materials and equipment. The following information was obtained from Magnaflux Corp; Chicago, Ill.: They have no detailed information on the use of magnetic particle inspection underwater. However, they have a standard kit for use at exterior locations in the rain (developed for the pipeline industry) which could be modified for underwater use fairly easily. The biggest special feature is waterproofing of the magnetizing yoke (which operates on 110V). Visual technique is used with a black powder brush-applied as a slurry. A white light would be needed for underwater use.

A variant of the MT method uses an adhesive magnetic tape which is placed over the area to be inspected. After magnetization, the tape which now contains indications (if present) is stripped and examined by a special device. The tape may be regarded as a permanent record. Provided that both ends of the tape and perhaps additional intermediate points are accurately indexed with respect to location on the hull, individual locations can be accurately mapped. It is understood that a European organization is developing this technique for underwater use. This would be a useful development since it would reduce the amount of work to be done underwater and the judgement function would be performed in the optimum environment.

E.3.6.4 Navigational Concerns

Diver navigation is a primary problem, often due to poor visibility. Hogging lines, run from side to side underneath a ship and with marking along the length to assist in location finding, are used regularly. Weld seams may be followed to locate a position if the distance is not too great.

An improved method of underwater position finding is badly needed. This actually a two-part problem involving both point position finding and monitoring area coverage. Sea chests, for instance, may be located by defining a point position. The submarine critical discharge opening mistakenly closed off by a tender diver would not have been capped if his position was better known. Area coverage would be used in cases involving hull cleaning and inspection. The two hull openings missed after diver inspection of NEWPORT NEWS would have been found had the areas covered been monitored and recorded.

Automated systems such as SCAMP (Appendix D) require some sort of additional guidance when cleaning flat horizontal surfaces since water depth pressure cannot be used to guide the vehicle in this case.

Several methods have been suggested which will improve this situation. Most involve visual aids such as underwater grid lines, frame markings, and numbering systems. A numbering system is recommended in any case and especially in areas where mistakes may easily be made, such as locations where there may be several similar sea chest openings in a small area. Grid lines and frame markings are effective, but may aid a hostile diver as well. A sonar navigation system, involving two passive

E.3.6.4 Navigational Concerns (Continued)

transducer reference pingers and a diver or vehicle held active transducer position indicator would work under all conditions. This system also offers the option of creating a permanent graphic record of the areas covered. The technology to build a locator system such as this exists, but has not been directed to solve this particular problem. Accuracies within three inches in 600 feet are within the capability of this type of system.[30]

The provision of a clear water maintenance facility as proposed by section E.3.2.4 would alleviate the navigational problem and make all other underwater tasks easier as well.

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