EPRI Leadership in Science and Technology

REPORT SUMMARY

Underwater Maintenance Guide: Revision 2

A Guide to Diving and Remotely-Operated Vehicle Operations for Nuclear Maintenance Personnel

The use of water in nuclear power generating stations, both as an effective radiation barrier and thermal transfer medium, is critical to basic station operations. Consequently, underwater services play an important role in the maintenance and repair of these stations. Revision 2 of this guide expands previous discussions on underwater maintenance and provides new information on underwater welding and cutting operations and tasks.

INTEREST CATEGORIES

Maintenance practices
Nuclear plant operations
and maintenance

KEYWORDS

Diving
Repair
Robots
Underwater maintenance
Underwater vehicles
Welding

BACKGROUND An increasing variety of applications has developed for underwater services through the replacement of older methodology and the creation of new approaches to existing problems. The need to document these various applications of underwater services by utilities, as well as to develop a general introduction to these services and their performance guidelines, has prompted the preparation of this guide.

OBJECTIVE To provide a single-source reference covering diving and remotely-operated vehicle operations in nuclear maintenance applications.

APPROACH This second revision to this guide builds upon previously published work by incorporating new information which addresses underwater welding and cutting [burning] operations. The project team conducted an extensive literature survey of both domestic and international information on underwater welding and cutting, visited vendor facilities, and interviewed industry personnel experienced with underwater welding and cutting technology and operations. The NMAC staff updated existing guide information and integrated the new information into this second revision.

RESULTS The guide presents a general introduction to both diving and remotely-operated vehicles. It provides an overview of many of the various types of underwater operations found in nuclear maintenance applications, as well as general performance guidelines for many of the principal maintenance tasks which occur underwater at nuclear plants. Appendices contain a wide range of general reference information.

NMAC PERSPECTIVE This guide provides a basis for the continued development of documentation covering the planning considerations, operational support requirements, and performance guidelines relating to underwater services. Future revisions of the guide will provide additional sections of information on new topics and refine existing information. Information provided in this guide will assist maintenance personnel in more accurately planning and managing underwater maintenance, thereby providing an opportunity to increase both project safety and cost-efficiency.

PROJECT

RP-2814-24

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Nuclear Maintenance Applications Center

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A Guide to Diving and Remotely Operated Vehicle Operations for Nuclear Maintenance Personnel

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ABSTRACT

The use of water in nuclear power generating stations, both as an effective radiation barrier and thermal transfer medium, is critical to basic station operation. Consequently, underwater services, whether by diving intervention or remotely-operated vehicle (ROV), play an important role in the maintenance of both primary and secondary systems in nuclear power plants. This *Underwater Maintenance Guide* provides nuclear plant maintenance personnel and the technical reader a basic appreciation and understanding of underwater services.

The guide presents an introduction to both diving and ROV services. This includes a general discussion of these services, their personnel and equipment, and information on general diving and ROV operations. Operational guidelines for specific underwater work tasks such as high-pressure waterblasting, metal-cutting, and wet welding are also presented, as are guidelines for individual primary and secondary system maintenance tasks for both PWR and BWR plants. The guide also contains a number of appendices providing a single-source reference of various information on underwater welding & cutting, underwater services contractors, ROV equipment manufacturers, and diving decompression tables, as well as a glossary of terms and bibliography of related information.

INTRODUCTION

This Underwater Maintenance Guide has been developed to provide utility plant personnel a single-source reference to underwater services. These services, which include both manned diving and remotely-operated vehicle operations, are required to perform certain underwater maintenance functions at nuclear power generating stations. This guide provides an introduction to those underwater services and their general operations, as well as overviews of specific work tasks which have been identified thus far. This information is intended to familiarize utility maintenance personnel with the general scope and capabilities of underwater services, without encroaching upon the contractor's flexibility to develop responses to individual maintenance tasks.

As an introduction to underwater services, this guide will provide the framework to which additional information on general operations and specific maintenance tasks will be added, on a continuing basis. Like the information contained in this volume, future information will be collected for inclusion from both utility maintenance personnel, underwater services contractors, and equipment manufacturers. To gather the information necessary to create this initial document, announcements were prepared and distributed to all EPRI-member utilities and many underwater services contractors in the United States. Additionally, an announcement was published in the trade journal of the Association of Diving Contractors. Surveys were prepared and distributed to all EPRI-member utility maintenance managers, and many known underwater services contractors, requesting information on their underwater nuclear maintenance applications. From the utility responses, further underwater services contractors were identified, contacted, and surveyed. Where possible, specific project information was cross-referenced and checked for accuracy with both the individual utility and the contractor. Equipment manufacturers were also contacted for information pertaining to equipment utilization, maintenance, and technical specifications.

The guide begins with an introduction to both types of underwater services and continues with discussions of both general underwater operations and specific maintenance tasks. Those general operations covered consist of underwater tasks which are basic to all underwater operations. They are included to provide the reader with an appreciation of operations which can be carried out underwater, as well as considerations concerning their manner of operation. The specific work tasks contained in the guide may occur in both pressurized and boiling water reactors, and in both the primary or secondary systems. These specific maintenance tasks cover the basic underwater maintenance tasks occurring at utilities, as defined by utility and contractor survey responses. Overviews of additional tasks will be added as they become available. The appendices contain a current listing of underwater service contractors providing services to the nuclear industry. The listing is accompanied by a chart showing their general capabilities, as well as their prior experience in the nuclear sector. Descriptions of several remotely-operated vehicles and equipment used in nuclear inspection work are contained in the appendices, as are U. S. Navy Standard Air Diving decompression and related tables, information on underwater repair welding, case histories, a bibliography of related writings used in the preparation of this guide, and a glossary of technical terms.

Nuclear maintenance personnel will find this guide useful in gaining a better appreciation of the requirements which govern their diving and remotely-operated vehicle operations. The information presented in chapters one and two should assist the reader in gaining an understanding of the personnel and equipment requirements for diving and ROV operations, as well as related operational considerations. Chapter three, on underwater operations, will assist the reader in the planning and management of general diving operations, while chapter four will provide the reader with an overview of the performance criteria covering certain maintenance tasks which may occur at their plant. Chapter five, the appendices, will provide the reader with detailed information on the location and evaluation of diving contractors and ROV equipment, based upon performance requirements, for their specific applications. The U. S. Navy Diving Decompression Tables can be used to assist maintenance personnel in planning manning levels for projects and in verifying some performance factors associated with diving operations. The section on underwater repair welding provides information on underwater welding and cutting operations and tasks. The interested reader will also find the case histories, bibliography, and glossary of technical terms of further assistance in gaining an in depth understanding of certain facets of underwater services.

As previously stated, this guide is intended to serve as a basis for further development. The cooperation shown in its development, by both utilities and underwater services contractors, is greatly appreciated. It is hoped that the publication of this volume will serve as a catalyst which will spur increased cooperation by all concerned, from which a major compendium of information on nuclear underwater maintenance will eventually develop.

ACKNOWLEDGEMENTS

This guide was initially prepared for the Nuclear Maintenance Applications Center (NMAC) under Electric Power Research Institute research project number RP2814-24. This publication marks the second revision to the guide. NMAC would like to acknowledge the extensive information and assistance provided by the electric utilities, underwater services contractors and underwater equipment manufacturers, as well as specific information on underwater welding and cutting operations compiled and contributed by EPRI Repair and Replacement Applications Center staff. Also, the time and attention provided by each of those persons participating in the draft review is gratefully appreciated.

As with the preparation of any document of this scope, numerous individuals come to mind who have either given exceedingly of their time during the course of this project, and or provided both information and critical assistance necessary to the successful production of this Guide. NMAC would like to take this opportunity to recognize some of those persons individually, for their various contributions.

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Roger Swain, *Thyssen Welding Products/Welders Supply*

Randy Thompson & Jack Couch, *Oceaneering International, Inc.*

Owen T. Williams, *Consultant*

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Chapter 1

Diving Services

1. DIVING SERVICES

This Chapter presents a general introduction to diving services; their personnel and equipment requirements. It also presents general information covering the planning and conduct of, successively, general diving operations, contaminated water diving operations, and radioactively-contaminated water diving operations. Information presented for each set of operations is assumed to be in addition to information presented covering previous guidelines of this Chapter.

1.1. Overview

For the purposes of this guide, diving services are defined as those services provided which use direct, manned intervention underwater, to accomplish a pre-defined work task. In general, references to diving services in this guide are directed towards *surface-supplied* diving operations, and *not SCUBA* diving. Surface-supplied diving consists of the use of a diving helmet or full-face mask, to which compressed breathing gas and communications are provided, via an *umbilical* from the surface. SCUBA is diving which is conducted using a Self-Contained Underwater Breathing Apparatus. This device consists of compressed air tanks worn by the diver, attached to a two-stage regulator. Scuba diving has a limited use m commercial diving operations, due to:

- Limited air supply
- Lack of available *standby* breathing gas source
- Increased respiratory exertion
- Lack of direct communications capabilities
- Loss of direct physical contact with the diver

It does, however, provide a low cost and effective alternative means of performing certain underwater tasks to which it is operationally suited. These tasks should share all of the following characteristics:

- Performed only by experienced and <u>certified</u> individuals
- Inspection or light-work duty only
- <u>Visual contact</u> with diver maintained by topside support personnel
- Not requiring topside support or communication
- <u>Limited</u> number of dives planned
- Clear and direct line of ascent to the surface
- *Bottom times* within *no-decompression* dive limitations

As indicated, SCUBA should be performed only by individuals trained and certified by one of the nationally-accredited agencies, such as the National Association of

Underwater Instructors (NAUI) or the Professional Association of Diving Instructors (PADI). If used within the above parameters, it can provide an efficient and cost-effective means for the accomplishment of underwater tasks, particularly those requiring rapid response.

In the United States, there are dozens of marine contractors, each providing various levels of diving services to clients. From these, about eighteen underwater services contractors are now actively providing services to the nuclear industry. This fact was determined from surveys of both underwater services contractors and utility maintenance management. More than forty contractors and sixty utilities were contacted and asked to provide detailed information on their prior experience in underwater nuclear maintenance. The result was a compilation of information on underwater services contractors found to be providing services to the nuclear utility industry. These contractors are listed in Appendix I, accompanied by a chart presenting additional contractor information.

Providing contaminated water diving services distinguishes underwater diving contractors in the nuclear industry. As a rule, those contractors providing these services do so as an adjunct to their general diving services, which normally require less stringent operations planning and less specialization of equipment and personnel.

The contractors providing services to the nuclear industry are located mainly along the East coast of the United States and in the Gulf South, although several have of rices in the central and western parts of the United States, as well. They vary in size from small independent diving contractors servicing a single nuclear client, to large full service marine contractors providing a wide range of services and capabilities to clients in diverse industries.

In this chapter, we shall examine the three (3) individual parts which collectively make up diving services. They are personnel, equipment, and operations. The following section on personnel gives a listing of each of the job classifications typical of those found in commercial diving operations, accompanied by a brief description of their duties and responsibilities. The equipment section gives an overview of the basic pieces of equipment necessary to support commercial diving operations. Specific requirements covering personnel and equipment are provided in the Marine Occupational Safety and Health Standards (10 CFR, Part 197, subpart B) and Occupational Safety and Health Standards (29 CFR, Part 1910, subpartT), established by the Occupational Safety and Health Administration (OSHA). Finally, the section on operations is subdivided into two parts. The first part discusses the conduction of general diving operations, while the second deals with contaminated-water diving. The section concerning contaminated water diving operations is further subdivided into general considerations, and those specifically applying to radioactive contamination.

The information contained in this chapter will provide the unfamiliar reader with both a general understanding of diving services, through a logical presentation of the subject matter, as well as a familiarity with the organization and application of these services.

1 .2. Diving Personnel

1.2.1. Introduction

As with many operations, the diver is aided by a variety of support personnel in the performance of an operation. These personnel consist of a *diving supervisor*, a standby diver, and several *diver-tenders.* Depending upon the scope and complexity of the work, there may be additional members of the support team who provide help in other areas.

1.2.2. Tender

The tenders are those individuals who are most often responsible for the actual onsite preparation and performance of surface support activities. They set up the equipment at the job site, under the direction, and according to the equipment layout specified by the diving supervisor. They routinely perform many of the pre-dive equipment checks, help the diver and standby diver in dressing, entering/exiting the water, tending their umbilical(s) while in the water, and providing many other direct diver support functions during each dive. Typically, one tender each will be designated to support the requirements of the diver and standby diver, during a dive. During surface decompression treatment, the tender is usually the person-in-charge of the chamber operations, though directed and overseen by the diving supervisor. Tenders perform an important safety function as well, throughout the course of a diving operation, by maintaining the general order and cleanliness of the work area, and in final equipment demobilization and cleanup of the work site. While experienced tenders may, from time to time, be allowed to perform routine dives by the diving supervisor, their use in this fashion should not be anticipated in lieu of a requirement for an additional diver to support planned operations. Tenders are responsible to the diving supervisor for their instruction.

1.2.3. Diver

The diver is that individual who performs the actual underwater work tasks. In general, he will have served some term of an apprenticeship as a tender, before becoming a diver. A diver's skill centers in his mechanical ability to perform work in an underwater environment. However, many divers have received additional training in other areas, such as welding, non-destructive testing, photography, or emergency medicine. The underwater environment differs significantly from the standard surface operating environment. However, most work tasks which can be accomplished in a dry environment can also be accomplished underwater. It is usually the diver, with the diving supervisor and others, who evaluates individual work tasks within the overall *scope of work,* and develops the plan for their performance during his individual dive. The diver is directly responsible to the diving supervisor for his instruction.

1.2.4. Standby Diver

The standby diver is that individual who is responsible for maintaining a state of readiness to dive, in the event that the diver(s) in the water require immediate assistance or emergency rescue. The standby diver should have no other operational responsibilities which would conflict with this primary function. As part of this responsibility, the standby diver should understand the scope of work to be performed during the dive, by the diver, as well as monitoring the progress and condition of the diver throughout the course of the dive. The standby diver reports directly to the diving supervisor.

1.2.5. Diving Supervisor

The diving supervisor is that individual who is responsible for all planning and performance of diving operations for a given project. In addition, he is appointed by his company as the person-in-charge for client interface, during the performance of diving operations on a project. The role of the diving supervisor is to manage and direct both the surface support operations as well as the performance of each diver, for his company and the client. He is also responsible for maintaining the project operations chronology, daily cost-accounting, and other required forms of project documentation. The diving supervisor also serves the client in providing onsite technical consultation, related to the underwater operations of the project. The diving supervisor is responsible to his company's operations manager.

1.2.6. Operations Manager

The operations manager is that individual at the underwater services company who is most directly responsible for all facets of the management and administration of a diving services contract for the company. It is his function to propose the level of diving services required by the client for a particular application, and to mobilize the diving personnel and equipment necessary for each project. Further, the operations manager is responsible for administration of all project requirements, and provision of all logistical support effecting diving operations.

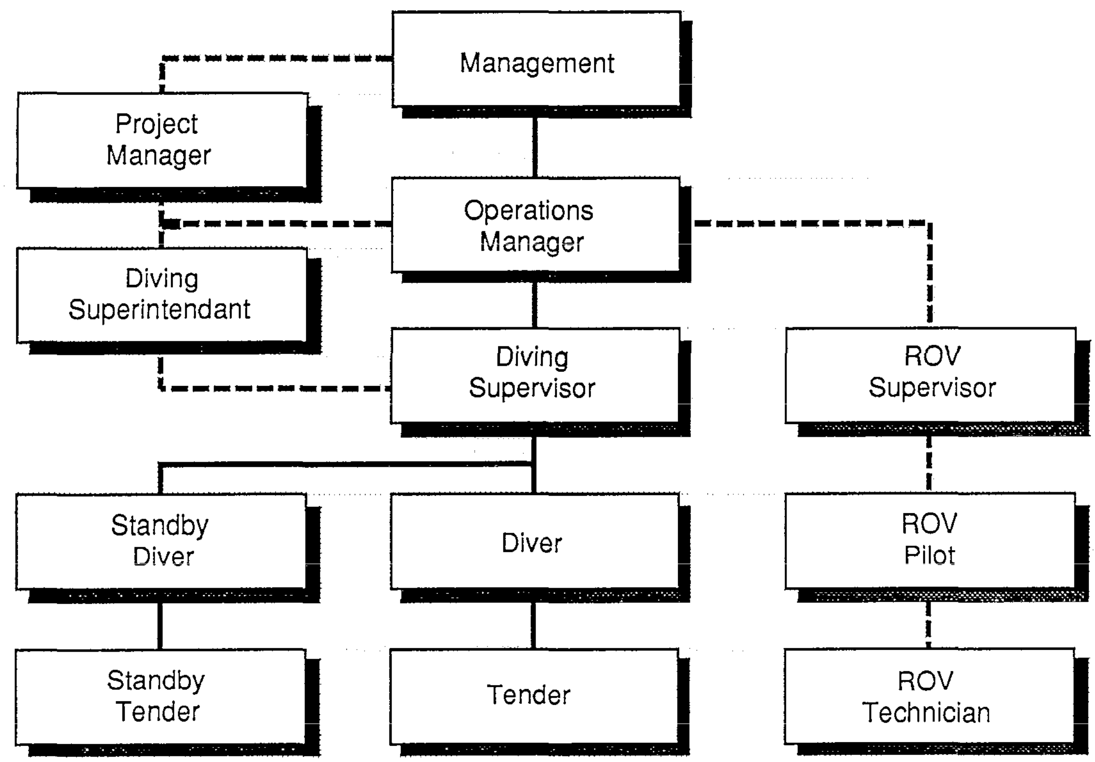
1.2.7. Diving Superintendent

In projects of large scope or extensive duration, there may be more than one diving supervisor required to support project operations, such as in around-the-clock [24 hour] activities. In this case, each diving supervisor may be responsible to an onsite *diving superintendents* It is his responsibility to oversee all diving operations, and to provide the diving supervisors with relief from their administrative functions. This allows them to concentrate their efforts on their operational roles. In this circumstance, it is the diving superintendent which is responsible to the operations manager.

1.2.8. Project Manager

In projects of large scope or duration, where there is a significant degree of complexity, or where diving services represent only a single facet of the overall operations, a diving superintendent might be responsible to a project manager. This project manager is a line-manager, with full management responsibilities, and usually functioning at the same level as the company's operations manager, but with responsibilities limited to a single project.

Following in Figure 1-1, is a typical organizational chart for the personnel classifications of a diving services contractor. The chart displays each of the previous personnel groups, and their interrelationship, according to usual lines of authority.



DIVING SERVICES CONTRACTOR
Typical Personnel Organization Chart
Figure 1-1

1.3. Diving Equipment

1.3.1 . Introduction

One of the cornerstones leading to safe and productive underwater operations by contractors is in their use of reliable operating equipment. This reliability comes primarily from good equipment maintenance practices. Contractors should be able to demonstrate an effective equipment maintenance program in place, and provide examples of their equipment maintenance schedules. Life support equipment, by regulation, has certain standards for performance and testing which are mandated. In support of these requirements, the contractor should be able to provide proper documentation which indicates that their equipment meets these existing standards, and that they are in compliance with existing regulations governing equipment performance and testing.

The design, construction, and use of equipment in support of commercial diving operations is covered by Marine Occupational Safety and Health Standards (10 CFR Part 197, subpart B) and Occupational Safety and Health Standards (29 CFR Part 1910, subpart T). Subpart B specifically applies only to those operations conducted offshore. or aboard a vessel which requires U. S. Coast Guard inspection regardless of location. Subpart T specifically applies to every place of employment within the waters of the United States...where diving and related support operations are performed. The following sections offer a synopsis drawn from those standards, which relate to diving equipment found in use in nuclear maintenance applications.

1.3.2. Air Compressor System

A compressor used to supply breathing air to a diver must:

- Be tested for air purity every six (6) months by means of samples taken at the connection to the distribution system, except that non-oil lubricated compressors need not be tested for oil mist.
- Have a volume tank built and stamped in accordance with Section VIII, Division 1 of the ASME Code, equipped with a check valve on the inlet side, a pressure gauge, a relief valve, and a drain valve.
- Be tested after every repair, change, or alteration to the pressure boundaries.
- Have air intakes that are located away from areas containing exhaust fumes of internal combustion engines or other hazardous contaminants.
- Have an effective filtration system. (Reference the section on Breathing Gas Supply: compressed air, for exact purity requirements).
- Have slow-opening shut-off valves when the maximum allowable working pressure of the systems exceeds 500 psig.

1.3.3. Breathing Supply Hoses

Each individual breathing supply hose must:

- Have a maximum working pressure that is equal to or exceeds the maximum working pressure of the section of the breathing supply system, or the pressure equivalent of the maximum depth of the dive relative to the supply source plus 100 psig.
- Have a bursting pressure four times its maximum working pressure, and be tested to 1.5 times their rated working pressure annually.
- Have connectors made of corrosion-resistant materials, which are resistant to accidental disengagement, and have a maximum working pressure that is at least equivalent to the maximum working pressure of the hose to which they are attached.
- Resist kinking by being made out of kink-resistant materials, or having exterior support.

Each umbilical must:

- Meet the preceding requirements for hoses.
- Be marked from the diver or open bell end in 10 foot intervals to 100 feet, and in 50 foot intervals thereafter. This can be accomplished by using a system of color coded tape markings.

An umbilical is defined as "the composite hose bundle between a dive location and a diver or bell, or between a diver and a bell, which supplies the diver or bell the breathing gas, communications, power, or heat, as appropriate to the diving mode or conditions, and includes a safety line between the diver and the dive location."

1.3.4. First Aid and Treatment Equipment

Each dive location must have:

- A medical kit approved by a physician that consists of basic first aid supplies, any additional supplies necessary to treat minor trauma and illness resulting from hyperbaric exposure.
- A copy of the American Red Cross Standard First Aid handbook.
- A bag-type resuscitator with transparent mask and tubing.
- A capability to remove an injured person from the water. (A diving stage is an excellent vehicle for this requirement, and can serve other functions, such as tool/material delivery).

Each diving installation must have a two-way communications system to obtain emergency assistance. In most in-plant operations, this requirement is not a problem. However, in the diving inspection of outside structures, particularly the Circulating Water System (CWS) intake structures, it is absolutely mandatory that two-way communications capabilities exist between the *dire station* and the utility control room.

Each dive location supporting dives deeper than 130 *fsw*, or dives outside the no-decompression limits must meet the preceding requirements of this section, and have

- A decompression chamber onsite.
- Decompression and treatment tables.
- A supply of breathing gases sufficient to treat for decompression sickness.
- The required medical kit that can be carried into the decompression chamber, and is suitable for use under hyperbaric conditions.
- A capability to help an injured diver into the decompression chamber.

1.3.5. Gages and Timekeeping Devices

A gage showing diver depth must be at each dive station for *surface-supplied* dives. In normal operations, it is good practice to have a standby gauge online to act as a backup and reference to the primary gauge. Each gauge shall be dead weight tested or calibrated against a master gauge every six (6) months, or when there is a discrepancy of greater than two (2%) percent between any two equivalent gauges.

A timekeeping device must be at each dive station. The timekeeping device should be clearly legible to the timekeeper, and a sweep second hand is desirable. As with the depth gauge, a standby timekeeping device, synchronized and used in tandem with the primary device, is good operating practice.

1.3.6. Diving Ladder and Stage

Each diving ladder must:

- Be capable of supporting the weight of at least two divers and their gear on one rung, or a minimum weight of 400 lbs.
- Extend 3 feet below the surface of the water. In outdoor dive locations where wave action might be found, the bottom of the ladder should extend 3 feet below the bottom of the lowest wave trough.
- Be firmly in place. It is particularly important in outdoor dive locations where water currents or wave actions are found, that provisions are made to firmly anchor the ladder, before and during use.
- Be available at the dive location for a diver to enter or exit the water, unless a diving stage or bell is provided.
- Be made of corrosion-resistant material, or be protected against and maintained free, from corrosion.

Each diving stage must:

- Be capable of supporting the weight of at least two divers and their gear, or a minimum weight of 400 lbs.
- Have an open-grating platform.
- Be available for a diver to enter or exit the water from the dive location and for in-water decompression, if the diver is wearing a heavy-weight diving outfit or is diving outside the no-decompression limits, except when a diving bell is provided.
- Be made of corrosion-resistant material, and protected against and maintained free from injurious corrosion.

1.3.7. Surface-Supplied Helmets and Masks

Each surface-supplied helmet or mask must have:

- A non-return valve at the attachment point between the helmet or mask and the umbilical that closes readily and positively.
- An exhaust valve. In contaminated water applications, the use of two exhaust valves in series is recommended to reduce back splatter and leakage into the helmet.
- A two-way voice communications system between the diver and the dive station.

Each surface-supplied air helmet or mask must:

- Ventilate at least 4.5 *actual cubic feet per minute* (ACFM) at any depth at which it is operated.

- Provide adequate ventilation, defined as being able to maintain the divers' inspired carbon dioxide partial pressure below 0.02 *atmospheres absolute* (ATA) when the diver is producing carbon dioxide at a rate of 1.6 standard liters per minute.

1.3.8. Divers Safety Harness

Each safety harness used in surface-supplied diving must have:

- A positive buckling device.

- An attachment point for the umbilical life line that distributes the pulling force of the umbilical over the diver's body, and prevents strain on the helmet or mask.

1.3.9. Oxygen Safety

Equipment used with oxygen or oxygen mixtures greater that 40 percent by volume must be designed and maintained for such use.

Oxygen systems with pressures greater than 125 psig must have slow-opening shut-off valves except pressure boundary shut-off valves may be ball valves.

1.3.10. Compressed Gas Cylinders

Each compressed gas cylinder must:

- Be stored in a ventilated area.

- Be protected from excessive heat.

- Be prevented from falling.

- Be tested after any repair, modification, or alteration to the pressure boundaries.

1.3.11. Breathing Gas Supply

A primary breathing gas supply for surface-supplied diving must be sufficient to support the following for the duration of the dive:

- The diver.

- The standby diver.

- The decompression chamber when required. . . for the duration of the dive and for one hour after completion of the planned dive.

- A decompression chamber when provided but not required.

A secondary breathing gas supply for surface-supplied diving must be sufficient to support the following:

- The diver while returning to the surface.

- The diver during decompression.

- The standby diver.
- The decompression chamber when required... for the duration of the dive and for one hour after completion of the planned dive.
- The open bell while returning the diver to the surface.

A diver-carried reserve breathing gas supply for surface-supplied diving must be sufficient to allow the diver to:

- Reach the surface.
- Reach another source of breathing gas, or
- Be reached by a standby diver equipped with another source of breathing gas for the diver.

Oxygen used for breathing mixtures must:

- Meet the requirements of Federal Specification BB-0-925a; and
- Be type 1 (gaseous) grade A or B.

Compressed Air used for breathing mixtures must:

- Be 20-22 percent Oxygen by volume.
- Have no objectionable odor; and
- Contain no more than 1000*/ppm* of Carbon Dioxide, 20/ppm of Carbon Monoxide, 5mg/m^3 solid and liquid particulates including oil, and 25/ppm of hydrocarbons. (includes methane and all other hydrocarbons expressed as methane).

1.3.12. Buoyancy-Changing Devices

A drysuit or other buoyancy-changing device not directly connected to the exhaust valve of the helmet or mask must have an independent exhaust valve.

1.3.13. Divers Equipment

Each diver using a light-weight diving outfit must have:

- A safety harness.
- A weight assembly [belt] capable of quick release.
- A mask [helmet] group consisting of a lightweight mask [or helmet] and associated valves and connections. Diving masks of various manufacturers may be suitable for use in non-contaminated waters, however, only diving helmets should be used for contaminated water diving operations.
- Have a diving dress consisting of wet or dry diving dress, gloves, shoes, weight assembly [belt], and knife.

- Have a [diving] hose group consisting of breathing gas hose and fittings, lifeline, communications cable, and a pneumofathometer. If the breaking strength of the communications cable is at least equal to that required for the lifeline, the communications cable can serve as the lifeline, providing it is securely married to the other components making up the umbilical. The pneumofathometer should not be used when diving in radioactively contaminated water.

Each surface-supplied air dive operation, within the no-decompression limits and to depths of 130 fsw or less, must have a primary breathing gas supply at the dive location

Each surface-supplied dive operation outside the no-decompression limits, deeper than 130 fsw, or using mixed-gas as a breathing mixture must have at the dive location:

- A primary breathing gas supply.
- A secondary breathing gas supply.

Each diver diving outside the no-decompression limits, deeper than 130 fsw, or using mixed-gas must have a diver-carried reserve breathing gas supply except when using a heavy-weight diving outfit or when diving in a physically confining area.

1.4. General Diving Operations

1.4.1. Introduction

From an operational standpoint, all diving operations have several requirements and procedures in common, which are considered as generic to the practice. At a minimum, each requires at least the following:

- A source of breathing gas, in most cases simply compressed air, for supply to the diver. If the breathing gas is provided by a compressor, as opposed to high-pressure cylinders, proper attention must be given to positioning the air intakes in an area free from exhaust fumes, airborne radiological and other contamination.
- A separate standby source of breathing gas for supply to the diver in the event of an emergency, such as loss or contamination of the primary breathing media
- An uninterruptable electric power supply for communications, often including automatic battery backup
- A dive installation, or dive station, consisting of all diving equipment necessary to support diving operations and personnel. It should be positioned in an area of free and clear access, as closely to the work site as practical.
- A selection of tools and other equipment, for use by both the diver and topside support personnel, necessary to perform each of the planned work tasks

- Personal diving gear, necessary to increase the ease and safety with

- Adequate surface support personnel to provide operations control and supervision, standby diver capability, and diver-tending support for both the diver and standby diver.

Since these basic requirements for operations are commonplace, a systematic procedure has developed for operations planning and implementation of basic diving services

1.4.2. Scope of Work

The initial task in operations planning is to develop a scope of work for diving services. These procedures cover the identification of those underwater tasks to be performed by diving services, along with any requirements relating to their performance. The following items should be included in a procedure:

- Identification and a detailed description of individual work tasks to be performed.

- Physical location of each individual work task.

- Performance criteria for determining successful completion of the work tasks.

- Special considerations for performance and safety.

- Timeframe and milestones for accomplishment of the procedure.

1.4.3. Pre-Job Planning

If necessary, a diving services contractor, or other outside technical expert, can be used to assist in the evaluation of the procedure, and development of the pre-job planning. This expert assistance should be included in project planning as early as practical. This will allow a joint review of the procedure, and subsequent attention to the following items:

- Development of an outline of the specification for the performance of the procedure, including key objectives, general performance guidelines, and required results.

- Potential radiation hazards and possible solutions for achievement of ALARA goals.

- Procedure for safety tagging and/or locking out of operating equipment at each dive location.

- Contractor equipment and personnel requirements to support the proposed operations procedures. These include requirements often overlooked, such as a staging area for preparation of the equipment at the dive location and methods for deployment and recovery of the equipment.

- Scheduling of the operations, and selection of a date and location for a pre-job meeting with the divers, the diving supervisor, and those utility representatives who will have lst-line responsibility for the performance of the work.

- Special pre-job considerations, such as personnel training, procedural development, and personnel, equipment, or materials availability, or existing conditions effecting the performance of the work.

- Listing of required materials, equipment, and tools to support operations.

1.4.4. Mobilization

During mobilization, the contractor will arrange for the equipment and personnel deployment to the job site. As an initial part of this process, all equipment destined for delivery to the job site will be checked by the contractor for readiness before delivery and installation. Operations personnel scheduled for the project will be informed of their pending mobilization, and instructed to prepare for duty. All arrangements for personnel transportation and maintenance will be made by the contractor.

1.4.5. Dive Site Installation

Upon arrival at the job site, and as early as practical, personnel will inspect all diving equipment delivered for the project for damage in transit. Plant Health Physics (HP) personnel should inspect all equipment for prior radiological contamination. This immediate examination will allow for the ordering of replacement equipment, if necessary.

After completing any needed pre-job orientation onsite, diving personnel should transport the equipment to the first dive location, according to plan. The work site should be visually surveyed for any obvious hazards or other obstructions which might impact the safety or performance of the surface support operations. Passing that, the equipment should be set up according to the diving supervisor's direction, and the utility representative in charge. After set-up, the diving equipment should be operated and inspected to insure its safety and operability. At a minimum, the following inspections should be made:

- Check all hoses, fittings, and connections for excessive wear or leakage. Leak detection at critical fittings and connections, such as for standby breathing gas supplies and oxygen systems, is easily accomplished through the application of a commercial liquid leak detector, or a 50:1 solution of liquid soap and water. Minute leaks will become immediately visible due to their production of gas bubbles.

- Inspect all air compressors for proper operation of the pressure control valve by checking one loading/unloading cycle of the compressor. Check compressor gauges for proper readings and operation. Check compressorfluid levels and refill to the required level before beginning operations. Drain all volume tanks, filters, and sight glasses of condensate.

- Inspect all gas regulators for proper operation. Tag regulators used for oxygen delivery as "Oxygen-Clean" or "Oxygen Use Only"

- Gauge all high pressure gas cylinders intended for use, such as those for emergency backup, and tag each according to its gauge pressure as it is placed on-line. Inform the diving supervisor of any high-pressure cylinders placed on-line which are found to gauge at less than 80% of their working pressure.

- Establish an uninterruptable power supply for all systems having life-support or safety applications. Accomplish this by using a redundant power supply from a separate source, or from a battery backup. Use ground fault interruption circuitry for all 110v-220v AC power sources feeding the surface support activities.

- Connect diving radios, or other communications equipment, via the diving umbilicals to the diver's helmet of first use, and test the communications link. Repeat this procedure using the equipment set up for the standby diver; that is, the standby radio, umbilical, and helmet, to complete the testing of the communications equipment.

- Review the tool and material lists required for each phase of the project, and place those tools and materials required by the diver at hand. The diver should inspect each for readiness, before his dive.

1.4.6. Pre-Dive Planning

After completing the transportation and installation of the equipment at the job site, the next step common to all operations is the planning of the actual diving operations. This requires the following actions:

- Identify all plant operations personnel, such as Control Room personnel, whose activities might impact diving operations and develop written procedures covering their actions before, during, and after diving operations.

- Development of a dive rotation and notification of the diving crew of this ordering. A dive rotation is the selection of the divers in the order in which they will be required to dive. Place divers who have special skills which will be required at specific junctures during the job, in rotation in such a manner as to mesh their order in rotation with the current requirement for that dive.

- Assessment of work tasks by the diving supervisor for the forthcoming dive(s) and development of a dive plan for the accomplishment of each task. Divide the procedure into general blocks of work, with amounts in each block targeted for completion on each dive. Give consideration to the manner in which each block of work will 'blend' in with the successive block.

- Development of equipment and material requirements for each dive, before beginning that dive. All equipment and tools should be fully-configured and tested by operation at the surface, in as far as is practical, then laid at the ready by surface support personnel. Evaluate the usefulness of fixed-length tethers for use in managing underwater tools and equipment.

- Ensure that the diver personally inspects all equipment which he may use during a dive, and that he is familiar with both its configuration and proper operation. If in doubt, have the diver demonstrate to the diving supervisor, through discussion or actual demonstration, his familiarity with those tools or equipment in question.

- Ensure that the diving supervisor inspects materials required for each dive and accounts for them as they are used. Suggest that he maintain a tool issuance and recovery list for all tools which are used.

- Discuss the deployment and recovery methods for all equipment, tools, and materials with the diving supervisor. Define an agenda before the beginning of the dive. These points are especially important when diving in waters having poor visibility or physical factors which might inhibit the work process, such as currents or underwater obstructions.

- Notify all plant personnel having an interest in the planned operations, or in the control of systems whose operation might affect, or be affected by, the underwater operations, of the intent to begin operations. The notification should include the starting time and location of the operations, an estimated time to completion, and the name and contact number of the plant person in charge. This will allow easy confirmation of the status of operations by all departments.

- Identify plant operating systems which will require tagging out and locking during underwater operations. Develop a procedure for assuring that these systems are, in fact, tagged out and locked during operations. Use locks on electrical breakers, control valves, and equipment whose use might represent a hazard to diving operations.

- Discuss special considerations, such as critical procedures, potential hazards, or other safety concerns with the diver, standby diver, and diving supervisor, before beginning the dive.

1.4.7. Pre-Dive Inspection

Before beginning operations, the diving supervisor will inform the diver and standby diver of that portion of the procedure to be undertaken for a particular dive. Both the diver and standby diver will prove their understanding of the scope of work for each dive, in their discussion with the diving supervisor, before beginning the dive.

Perform the following checks before allowing the diver to enter the water:

- Inspect and verify in writing that all safety tags and locks placed upon electrical breakers, control valves, and equipment are secure and in place.

- Dressing-in of diver, including inspection of all seals and fasteners used.

- Inspect all personal diving equipment, including the diving dress, helmet, harness, knife, quick-disconnect shackle, and miscellaneous equipment.

- Test the two-way communications link between the diving supervisor and each diver.

- Inspect, test, and reset the timekeeping and depth-monitoring devices.

- Check any batteries or battery backups used in support of operations.

- Provision of a safe and efficient means for the diver to enter and exit the water, from the dive location.

- Notify all concerned parties of the readiness to begin diving operations and their expected schedule.

1.4.8. Operations

Upon his entering the water, provide the diver with enough slack in his diving umbilical to avoid immediately restraining the diver's movements. This is particularly important in open water areas outside the plant, where the diver's mode of entry (such as a jump or dive) or wave action, might reduce the effective amount of slack in the umbilical. This would place an undue strain directly upon the diver. After entry, the diver will orient himself and perform final system checks on the surface, before descending to the work site.

During the conduction of actual diving operations:

- Maintain regular communications with the diver, while paying particular attention to the quality of the diver's voice and breathing patterns. These provide general indications of the physical condition of the diver. Slurred or incoherent speech is a reliable sign of physical disability on the part of the diver, and may result from a variety of causes. Prolonged, rapid breathing on the part of the diver can be a precursor to overexertion, as well as a sign of several other conditions, each of which may require special attention by the diving supervisor.

- Pay close attention to the depth of the diver, monitoring it during initial descent, and from time to time thereafter. It is especially important to watch the diver's depth during movements away from the work site.

- Establish the physical location of the diver at all times, through communication with the diver, and verified by alternative methods if available.

- Relay changes in the physical relationships of objects in the work environment, resulting from the movement of equipment or materials, the diver, or the vessel (if applicable), to the diver. Take these changes into account in assessing the work, and evaluate all changes in the work environment, which effect the diver or the surface support crew, for their potential impact on operations.

- Monitor changing levels of consumables used during operations, such as compressed gases, systems fuels, battery power levels.

1.4.9. Project Documentation

During each dive conducted in commercial diving operations, a common series of events take place. Record each event in the project diving log, as follows:

- Left Surface Typically abbreviated in the diving log as (L/S). The diving supervisor, using two separate timekeeping devices, will record this time in the diving log. The duration of the dive begins at the point when the diver announces he has left the surface.

- Reached Bottom. Typically abbreviated in the diving log as (R/B). The diving supervisor will record this time in the diving log to show the time at which the diver actually arrived at the work depth, regardless of whether it is actually "on bottom".

- Left Bottom. Typically abbreviated in the diving log as (L/B). The diving supervisor will record this time in the diving log to show the time at which the diver actually began his ascent to the surface, from the work depth

- Bottom Time. Typically abbreviated in the diving log as (B/T). This represents the period from L/S to L/B, and is determined in commercial diving operations by the lesser of either 1) the time necessary to successfully complete a task, or 2) the limitations of the applicable decompression schedule which the diver must follow, based as a function of time vs. depth.

- Reached Surface. Typically abbreviated in the diving log as (R/S). The diving supervisor will record this time in the diving log to show the time at which the diver actually returned to the surface.

These five elements, along with decompression which will be only briefly addressed in this guide, make up the *dive profile*. Development of a projected dive profile for a series of dives is useful in preparing an estimated work schedule in support of general operations planning.

Each dive profile becomes part of an overall *project chronology*. This chronology details significant events which occur during the project, as a function of time. Events related to the underwater work, such as the five items listed above, and descriptions of work accomplished during each diver's bottom time should all be documented. Also document significant events associated with surface support activities.

In summary, successful diving operations are accomplished by thoughtful pre-planning and attention to detail in developing and following the operational procedures prepared for the procedure. A series of common sequences and events have been shown which are generic to virtually all diving operations, regardless of location or other contributing factors. Persons involved with the evaluation and implementation of diving services can make use of these as a guide.

1.5. Contaminated Water Diving

1.5.1. Introduction

In nuclear power plants, there exist several maintenance areas where underwater operations are performed using diving services. Within the context of this guide, those operations are subdivided into two (2) general groups, according to whether they are conducted in contaminated, or non-contaminated bodies of water.

Some maintenance areas are common to all nuclear power generation plants, while others are specific to either Pressurized Water Reactor (PWR) plants or Boiling Water Reactor (BWR) plants. In the previous section, we discussed the performance of general diving operations. Several sequences and events were noted which apply to all diving operations. In the nuclear environment, diving operations in contaminated water areas will require additional precautions beyond those previously outlined for general diving operations.

In the nuclear environment, we tend to associate contaminated water with radioactivity. Keep in mind that other sources of water contamination which are non-radioactive can also be found, and would affect how diving operations in those areas are performed. Some examples of radioactively contaminated water areas are:

- Spent Fuel Pools (SFP)
- Reactor suppression pools
- Fuel transfer tunnels
- Reactor and reactor cavity
- Torus areas
- Steam separator and dryer storage pools

An example of an underwater maintenance area contaminated from sources other than radiation might be the Circulating Water System (CWS). Environmental contamination may exist in a water source of questionable water quality, such as a polluted river or bay. This type of non-radioactive, contamination is caused by the elevated presence of several distinct factors, such as:

- Hydrocarbons, from oily discharges and spills by marine vessels, and various solvents from industrial waste.
- Heavy metals, such as lead, arsenic, zinc, cadmium, copper, chromium, iron, and manganese, from urban runoff in densely populated areas having high automobile usage.
- Fecal coliforms, principally from the discharge of raw or ineffectively treated sewerage in urban population areas, and from agricultural runoff in beef and dairy producing areas.
- Hazardous chemicals, usually occurring from the improper disposal of hazardous waste materials in or near localized water systems.

The information in the following sections is based upon the general experiences of underwater diving services contractors active in the nuclear diving industry. In the final analysis, plant health physics personnel should make the final determination on approved procedures, based upon individual plant policies and guidelines.

1.5.2. General Guidelines

Contaminated water diving services are differentiated from the norm by a requirement to isolate the diver from any direct physical contact with the water. Radiation and contamination hazards require additional precautions. These include monitoring and limiting the exposures received by the divers and diving support personnel to acceptable levels during diving operations.

As with general diving operations, in contaminated-water diving, there are several procedures and courses of action to take which will ensure the diver's safety, regardless of the source of contamination. They include:

- Dressing the diver in a drysuit, instead of a conventionally-used wetsuit, to eliminate the diver's physical contact with the contaminated water. With environmental contaminants, it is very important to determine their exact nature, to be sure they are compatible with the drysuit material and seam glues used. This will prevent the contamination of the diver by the accidental failure of the suit material or seams.

- Use of a diving helmet, as opposed to a diving mask of some type. This will offer full enclosure and protection of the diver's head by attachment directly to the drysuit, providing a watertight seal.

- Careful attention to gas exhaust valve designs used in the drysuit and diving helmet, to be sure that each provides a positive seal. A pair of exhaust valves, mounted successively, is most effective in stopping back splatter and leakage past the valve(s).

- Implementation of rigid quality assurance test procedures to certify that unknown penetrations do not exist in the drysuit, diving helmet, and other associated items such as gloves. Inspect each piece of equipment twice; once before the diver's entry into the water, and a second time, after the diver's entry into the water, before his descent. Do this first by inflating the dry suit and checking for leaks, using some type of commercial leak detection liquid. Have the diver also pause to monitor his suit for any signs of leakage before beginning his descent.

- Restriction of the work site to non-essential personnel, particularly when the diver is entering or exiting the water, will reduce the chance of an error in the pre-dive inspections of the diver's equipment. It will also lessen the risk of exposure to contaminants for those persons.

1.5.3. Radioactive Diving Guidelines

In addition to previous guidelines for general diving operations and operations in contaminated waters, the following are additional guidelines for diving in radioactive environments, such as those found within the nuclear plant:

- Issue a Radiation Work Permit (RWP) for all personnel.

- Each diver should complete a whole body count upon reporting to the job site, and before reporting to the dive location for work.

- The ideal water temperature at the diver's work site should range between 70°F-80°F, with 87-F being optimal. The temperature at the diver's work site should never exceed 95-F. Conduct a temperature survey at the diver's work site and along the path to the work site, prior to beginning diving operations. Plan to ensure that pool conditions, such as circulating water flows and temperatures remain constant while diving operations are in progress. Chilled water vests can be used to improve the performance and endurance of the diver required to work in uncomfortably warm water.

- Cover the floor of the dive location to prevent the spread of contaminated particles by equipment contact or personnel foot traffic. Construct temporary wall partitions around surface support area to reduce possibility of spreading contamination during operations.

- Supply pressurized, demineralized water to the dive location to rinse both the equipment and the diver, as they exit the contaminated water. If the decontamination rinsing is not performed over the pool, a provision for the collection and disposal of this water must be made.

- Provide waterproof boots, suits, hats, and gloves for all surface support personnel working in close proximity to contaminated water, as recommended by plant HP personnel or specified in the REAP. This clothing should be constructed from a non-porous material, covering the body from head to toe. Only paper suits or clothing made from natural fibers should be worn by others at the dive location, to reduce the chance of radioactive contamination in passing.

- For work conducted in the various radioactive pools located within nuclear plants, continue to flow pool water through the pool's filtration system to help maintain an acceptable level of underwater visibility for both the diver and topside personnel. Before beginning long duration projects, pool filtration, demineralizing, and resin systems should be checked and changed out as necessary, prior to beginning diving operations. Perform a pool chemistry analysis immediately before beginning diving operations, and again, at the end of each days diving activities.

- Monitor the pool's surface for increased radiation levels during diving operations where underwater surfaces may be disturbed. These disturbances can result in radioactive particles "floating" to the surface of the pool.

1.5.4. Health Physics Surveillance

Require HP personnel to conduct surveillance of the diving operations and diving personnel for radiation safety and safe operating practices. Appoint an HP supervisor to oversee radioactive diving operations from start to finish. The HP supervisor should appoint and supervise the actions of all HP technicians monitoring the diving operations, and independently check all exposure reading and records taken by the technicians during operations. In addition, the HP supervisor and technicians should:

- Perform a pool radiation survey before the beginning of diving operations. Produce a map of the pool detailing the depth, location, and radiation level of each source located. Use two independent methods of radiation survey. Repeat these surveys daily, before beginning diving operations, or after completing the movement of a radioactive source in the pool. In both cases, update the pool radiation survey map originally produced, to reflect the current status of the pool.

- Organize a daily briefing for diving personnel before beginning each days diving activities. Discuss the updated pool radiation map and survey status report. Develop details of the diver's planned work site(s) and work positions. Remind divers and diving supervisor of the need to report planned changes in either the diver's location or work position prior to making the change.

- Perform waterblasting or underwater vacuuming to reduce local radiation contamination before diving, as necessary.

- Evaluate the use of stainless steel shielding to reduce radiation exposures, and install as necessary.

- Evaluate the use of physical barriers and/or fixed-length tethers to reduce the possibility of entering, or dropping tools into, high radiation areas.

- As a general rule, restrict access to the dive station to only those personnel required to support operations, in order to reduce potentials for radiation exposures.

- Equip each diver, before his dive, with a calibrated alarming dosimeter or personal radiation monitor. Check these devices for proper operation each day, before beginning diving operations.

- Before each dive, see that HP personnel equip the diver with dosimetry devices according to plant guidelines In the absence of existing guidelines, a typical set-up might include two (2) finger ring TLD's and ten additional (10) TLD's, placed inside or outside of the diver's drysuit, at the following locations: two (2) finger ring TLD's, one each placed on one finger of each hand, two (2) placed one on each wrist (R/L), two (2) placed one on each ankle two (2) placed one each on each leg mid-thigh (R/L), and four (4) placed one each at the chest, back, head, and groin areas. The placement of Self-Reading Dosimeters (SRD) at each of the same points. Remote reading teledosimetry may also be considered where constant topside surveillance is desired.

- Maintain a separate record from the diving supervisor, of the various times associated with each dive.

- Request that the diving supervisor have each diver surface periodically, at convenient points during the operations, for inspection and checking of their dosimetry.

- Maintain visual contact with the diver, from point of entry through the entire dive, to be sure of his location and safe proximity to all known underwater radiation sources. HP technicians should suggest the best positioning of the diver at the work site, to reduce unnecessary radiation exposure to the diver.

- Survey the diver's suit and helmet for residual contamination not washed off upon his exiting the water, before releasing the diver to move to the contaminated changing area. The diving suit should not leave the pool area. This survey should be done as time permits, with consideration given to the safety of the diver and surface support personnel.

- Wash all diving gear and equipment removed from the pool with demineralized water as a decontaminant, and dry to prevent the spread of residual contamination. Rinsing of all diving gear and equipment removed from the pool should be done over the pool, if possible. Otherwise, a drainage area should be set-up to return rinse water directly to the pool.

- Immediately check the diver for contamination of the skin and hair upon removal of the diving gear. If background radiation levels do not permit this, direct the dressing of the diver at the dive location and accompany the diver directly to a separate changing area Conduct the survey in this separate area. In any event, conduct a survey of the skin and hair upon reaching the changing area.

- Monitor all diving equipment and tools removed from the pool, at the end of each dive, for contamination levels. Advise the diving supervisor of their continued suitability to service or need for replacement.

1.5.5. Divers Responsibilities

In addition to the pre-dive plans developed by the diving supervisor and others, and the monitoring and supervision provided by HP personnel on site, there are several areas in which the diver must assume primary responsibility. In these areas, the diver may be the first person to notice an event. In other cases, he may be the only person to notice an event. As such, the diver must assume the responsibility to tell the diving supervisor when he:

- Finds he has moved, or wishes to move, outside the pre-approved areas of the work site or along the pre-approved pathways of travel.

- Wishes to alter the preestablished dive plan to increase either his safety or effectiveness at the work site.

- Notices any change in either his environment (such as an increase in water temperature or current), or in his person (such as pain, dizziness, nausea, etc.), during or after a dive.

- Notices any change in the performance of tools systems, operating equipment, or life-support systems.

- Recognizes an operational requirement which has not been addressed.

- Recognizes a health or safety requirement has gone unnoticed, or is being improperly or ineffectively addressed.

Chapter 2

ROV Services

2. ROV SERVICES

This Chapter presents a general introduction to Remotely-Operated Vehicles (ROV's); their applications for use in nuclear power plant maintenance applications, their personnel requirements to support their operations, and a discussion of their various equipment components. Also included is a presentation of general ROV operating procedures covering all facets of ROV operations, from pre-dive preparation to post-dive maintenance.

2.1 Overview

2.1.1. Introduction

Remotely-operated vehicles are mobile underwater telerobotic systems used for various inspection tasks. They can be of use in both the primary and secondary systems of nuclear power plants. Their capabilities are subdivided into two general groups, inspection vehicles and mobile work platforms. At a minimum, each can provide high-resolution video monitoring and accurate depth sensing. Inspection vehicles are typically smaller, with limited payload capacity. Work platform vehicles, on the other hand, are defined by their greater size, propulsion, and payload capacity. In addition, work vehicles have some form of manipulative function, ranging from a simple Sanction grabber tool, to multiple, sophisticated, 9-function bi-directional force-feedback manipulators. These latter manipulators are able to mimic the approximate range of motion of the human arm. They can also perform relatively complex tasks, and lift objects up to 1000 pounds in weight. In nuclear maintenance applications, ROV's have proven useful in the following areas:

- Visual Inspection and Depth Assessment
- Loose Parts Retrieval
- Non-Destructive Examination
- Remote Dosimetry Reading
- Underwater vacuuming
- Diver Observation
- High-Pressure Waterblasting
- SONAR Profiling

2.1.2. Visual Inspection and Depth Assessment

In the underwater visual inspection of contaminated water areas, ROV's have proven extremely effective in providing detailed examinations of various components and structures. This represents a very cost-effective manner to meet ALARA goals and standards. ROV's are also capable of providing highly accurate depth sensing. This is required for the planning of certain diving operations, such as underwater welding procedures.

2.1.3. Loose Parts Retrieval

ROV's which are equipped with remote manipulators have also proven extremely effective in loose parts location and retrieval. Because they have the combined capabilities of video monitoring and manipulation, they are the next best alternative to diver's in this area. ROV's also do not have any of the liabilities associated with human radiation exposure.

2.1.4. Non-Destructive Examination

Ultrasonic testing, as well as other forms of non-destructive examination are performed quite adequately with the use of an ROV. The automatic depth sensing and video documentation of the discrete locations make ROV's are preferred method for this type of operation.

2.1.5. Remote Dosimetry Reading

In preparing for diving operations in remote locations of the primary system, an ROV can provide an excellent mechanism for determining relative radiation levels in specific areas, which the diver might expect to find.

2.1.6. Underwater Vacuuming

Equipped with an intake suction hose nozzle, leading back to an underwater vacuuming system, ROV's have been successfully used to decontaminate various areas and components. In this application, they are capable of entering areas, such as the fuel transfer tunnel. Divers may be unable to work here, because of close quarters and potentially high radiation levels.

2.1.7. Diver Observation

ROV's are used to record diver-performed underwater tasks for review and evaluation. Their presence also serves to support diving operations by allowing topside personnel to monitor the work site, leaving the diver free to concentrate on a specific task.

2.1.8. High-Pressure Waterblasting

In high-pressure waterblasting, ROV's equipped with jetting equipment, or with just the end unit [gun], are used to clean all manner of areas and components in both the primary and secondary systems. Larger work platform ROV's are used quite successfully to clean the intake screens and associated systems of marine growth.

2.1.9. SONAR Profiling

The capability of larger, work platform ROV's to carry acoustic positioning, sideman sonar, and sub-bottom profiling equipment enables them to perform a variety of tasks. Such tasks include mapping the bottom topography of intake canals to monitor sedimentation accumulation, and examination of the intake tunnels for cracking and debris accumulation.

ROV's are employed in both the primary and secondary systems, at both BWR and PWR plants. The following table in Figure 2-1, shows general areas of use for ROV's in each system.

Nuclear Plant ROV Applications Figure 2-1	
Primary System	Secondary System
Sparger Inspections	Circulating Water System Inspection
Suppression Pool/Torus Inspection	Condensate Storage Tank Cleaning
Steam Dryer/Separator Inspection	Intake Screen Cleaning
Foreign Object Retrieval	Intake Canal Basin Mapping
Miscellaneous Weld Inspection	Resin Tank Cleaning
Fuel Transfer Tunnel Inspection	Rad Waste Tank Cleaning
Reactor Vessel Inspection	
Pool Inspections	
Jet Pump Annulus Inspections	

2.2. Personnel

2.2.1. Introduction

ROV operations compared to diving operations, are relatively simple and straightforward, particularly in the area of personnel requirements. Utility maintenance personnel are easily trained in the proper and effective operation and maintenance of ROV systems. These systems are routinely bought for in-house use by utilities, for use in inspection operations.

Inspection ROV's require only 2-3 personnel to support operations. Maintenance operations, such as ROV waterblasting or vacuuming, may require 1-2 additional personnel to help in launching the vehicle, and in managing topside auxiliary equipment. In general, personnel are required to perform the following functions during the course of ROV operations:

- ROV Supervisor
- ROV Pilot
- ROV Maintenance Technician
- Data Recorder
- Surface Support Personnel

2.2.2. ROV Supervisor

The ROV supervisor may also be the pilot, as well, in small inspection operations. The supervisors duty is to integrate all the required ROV functions with topside support activities which are associated with planned operations. The supervisor will determine how operations are accomplished, their means of documentation, and the actions of those personnel required to assist operations.

2.2.3. ROV Pilot

The ROV pilot is responsible for the actual control of the vehicle, using a hand controller. Using this controller, the pilot refers to a video monitor which provides a picture from the ROV's camera. Using this method, the pilot can fly the vehicle directly to the area of interest, or along a predefined route, such as in a survey pattern. Working with the data recorder, the pilot guides the vehicle and controls any auxiliary on board systems, such as a manipulator. The ROV pilot reports directly to the ROV supervisor.

2.2.4. ROV Maintenance Technician

The ROV maintenance technician is the person primarily responsible for the launch, recovery, and maintenance of the ROV. He is also responsible for tending the vehicles' umbilical during operations, if necessary. This technician will perform all of the pre-dive and post-dive maintenance checkouts of ROV components, and tag all equipment as ready for storage and next-use. He will work in direct communication with the pilot to manage requirements during operations. The ROV Maintenance Technician reports directly to the ROV supervisor.

2.2.5. Data Recorder

The data recorder is the person charged with the management of the information acquisition and recording, during vehicle operations. His job is to organize the system required to document the operations, then work with the ROV pilot to obtain the required information. He then records it in the appropriate fashion. The data recorder reports directly to the ROV supervisor.

2.3. Equipment

2.3.1. Introduction

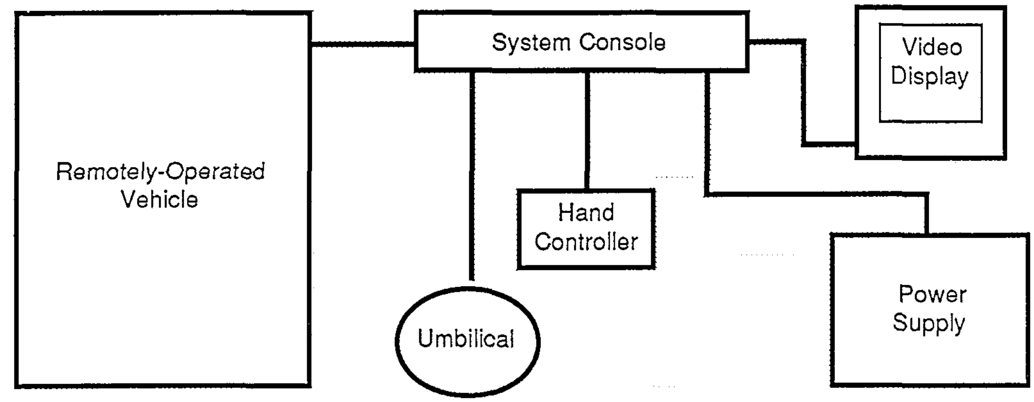
The equipment requirements for ROV systems generally fall into seven separate pieces of equipment, which include the:

- Power Supply
- System Control Console
- Video Display Monitor
- Remotely-Operated Vehicle
- Umbilical
- Hand Controller
- Vehicle Handling System

The system configuration for both inspection and work platform ROV's are similar, with the exception that many of the larger, work platform vehicles are deployed from a submersible garage. This garage is lowered to the proper working depth by a steel cable. It contains, in addition to the ROV, a sophisticated tether management system (TMS) which pays out and retrieves the umbilical to the ROV. This is done either automatically, or at the command of the operator. The following diagram displays a typical ROV system configuration.

TYPICAL ROV SYSTEM LAYOUT

Figure 2-2



Technical specifications for various ROV's used in nuclear underwater services are provided in Appendix II of this document.

2.3.2. Power Supply

The power requirements of smaller, electrically driven, inspection ROV's vary widely. They range from 110v single-phase to 440v 3-phase alternating current (a.c.) In general, a stable power source is required to maintain a steady video image from the vehicles' video camera.

2.3.3. System Control Console

The system control console serves to integrate each piece of the ROV system. It provides the electrical connection, interconnects, and switching capabilities required to support the operation of the system.

2.3.4. Video Display Monitor

The video display monitor provides the surface operator and support personnel with the important visual information necessary to operate the ROV. The monitor may be part of the system control console, but most often is a separate entity. It should have individual brightness and contrast controls, and an anti-glare screen coating is preferable. Its screen displays not only the video feed from the ROV camera system, but also generally provides a 'heads-up' video overlay of specific information associated with various ROV functions, such as:

- Depth/Altitude
- Compass Heading
- Thruster Speed
- Time/Date Stamps

2.3.5. Remotely-Operated Vehicle

Propeller/thrusters, camera and lighting systems, and buoyancy control devices are all mounted within the ROV framework. ROV's have thrusters m three separate orientations. These are required for the vehicle to move in all three planes. The camera system contains at least one forward-oriented camera system, mounted on a pan/tilt mechanism. The degree of camera pan and tilt depends upon the exact camera configuration of the particular vehicle. If the vehicle has a single camera, a black & white camera is usually selected, offering better overall visual acuity and lower-light image resolution. The thrusters are fluid-filled units capable of bi-directional rotation, which control the various movements of the vehicle. The buoyancy control device usually consists of a solid block of syntactic foam, overlayed with gelcoat. This gelcoat can become damaged, allowing contamination of the foam itself. For this reason, the foam is usually replaced with a hollow pressure vessel large enough to provide the necessary buoyancy to the ROV.

2.3.6. Umbilical

The umbilical which provides communication and control of the ROV is a specially made neutrally-buoyant, multi-conductor cable. It ranges upwards from about 3/8"-1" in diameter, depending upon the particular ROV system. The umbilical is ordered from the manufacturer in a variety of lengths, strengths, and configurations, and with a choice of external coverings to suit differing operations.

2.3.7. Hand Controller

The hand controller used by the ROV pilot to control the vehicle consists of a handheld box. It is fitted with 1-2 joystick controllers, and several other switches and equipment status lights. The joysticks control the various thruster motions and speed, as well as the pan/tilt mechanism of the camera system. It may also control the ROV lighting.

2.3.8. Vehicle Handling System

Smaller vehicles are capable of manual launch and recovery by 1-2 persons. Larger vehicles and umbilical systems may require the use of a davit, A-frame, or other lifting point. The larger work platform ROV's require a handling cage, or 'garage', for their deployment and recovery. This garage requires a steel cable and winch assembly on the surface.

2.4. Optional Equipment

2.4.1. Introduction

One of the chief advantages to ROV systems is their flexibility. ROV's are work platforms of opportunity, which can perform a range of tasks, by the addition of optional equipment. The table in Figure 2-3, on the following page, shows various specialty tasks to which an ROV can be adapted.

ROV OPTIONAL EQUIPMENT Figure 2-3	
Primary System	Secondary Systern
Remote Radiation Dosimetry	Side Scan Sonar
Radiation Tolerant Cameras	Dye Penetrant Crack Detection
Underwater Vacuuming	Sub-Bottom Profiling
Remote Manipulators	
Non-Destructive Examination Equipment	
35mm Still/Stereo Photography Cameras	
Color Video Cameras	
High-Pressure Waterblasting	

2.5. Operations

2.5.1. Introduction

ROV operations, as with diving operations, can be broken down into the following phases:

- Pre-Dive Preparation
- Equipment Set-Up
- Pre-Dive Functions Checkout
- ROV Operations
- Post-Dive Maintenance

2.5.2. Pre-Dive Preparation

In pre-dive preparation, we begin by thoroughly checking the condition of the vehicle. Perform a system check before each dive to confirm that all necessary maintenance has been completed. Once completed, the vehicle is ready for operations.

It is extremely important to remember that when handling the ROV, to give special care to protecting the cameras. This includes the clear hemispherical acrylic domes which protect the camera systems on some models. These domes are easily scratched, and care should be taken to avoid contacting their surfaces.

Disconnect the umbilical, if connected. Remove any protective fairings which might otherwise inhibit the general inspection of the lights, cameras, and thrusters. Check to be sure that:

- All locking hardware, such as hose clamps and closure straps, are tight.
- All O-rings are clean and well lubricated with silicone grease.

- The thruster shaft seals are in good condition.
- All set screws are set in place with an anaerobic-type thread-locking compound.
- Clear hemi-domes used to protect camera lenses are clean and free from surface scratches which might otherwise impair the camera vision.
- Any underwater plugs are connected, and that all contacts are clean and lightly lubricated with high-vacuum grease.

After reassembling the ROV, before connecting the umbilical connector, it is very important to check both the male and female connectors to be sure that both are completely dry, undamaged, and free of any debris. If moisture is present in this connection when power is supplied to the system, severe damage to the vehicles' electronics could result. Application of a moisture displacement spray for electronics parts is recommended for use in both connectors. Remove debris with a jet of low-pressure, dry air from a suitable source. Finally, inspect the condition of all O-rings in the connectors, and replace if necessary. Lightly lubricate the O-rings with silicone grease and carefully reconnect the umbilical to the ROV.

2.5.3. Equipment Set-up

In setting up the ROV dive station, position the system console and other components in a clean, dry area, as near to the ROV's point of entry into the water as practical. This will increase the usable umbilical length, and allow the pilot and maintenance technician tending the umbilical to maintain good communications.

Before connecting any electrical cables to the ROV system, be sure that all power switches on the power source, system console, and hand controller, are in the 'off position, and that all other controllers or switches are in the neutral or 'off position.

Inspect all connectors and cables, and particularly the umbilical cable, to be sure that each is in good condition. Inspect the umbilical closely to be sure that no cuts or defects exist in either its surface coating or connector housings. In general, the first fifty (50') feet of umbilical will show the greatest tendency towards wear. Place some type of fairlead over edges and around corners which the umbilical may contact, while on the surface, to reduce the potential of chafing.

After connecting all cables necessary to operate the ROV, turn on the power to the power source and vehicle console only. Check all status lights for proper illumination. Confirm that all hand controllers are in the neutral position.

Switch 'on' both the hand controller and the video monitor. Immediately recheck the ROV thrusters and hand controller to be sure that the controller is in the neutral position, and that the thrusters are not running in air.

2.5.4. Pre-dive Functions Checkout

It is good operating practice to perform a series of checks of major components, such as the cameras, lights, thrusters, and video display, before launching the ROV. This ensures proper functioning during operations.

Remember that neither the thruster motors, nor the underwater lighting systems used on most ROV's are designed to run in a dry environment. In both cases, their submergence provides a heat-dissipating effect which prevents damage to the thruster seals and high-output quartz-halogen lighting systems. In conducting the following tests, it should not be necessary to operate either the thrusters or lights more than a moment to be sure of proper operation. Never operate either system continuously in the dry for more than 30 seconds, without an interim cool-down period. Never test the thrusters at maximum speed.

Begin the pre-dive functions checkout by testing the operation of all the thrusters. Operate the hand controller and visually check the both the rotation and direction of each thruster. Proceed with the testing of the camera and lighting systems, as follows:

- Using the camera tilt control, tilt the camera fully up and fully down. During this step, check the video monitor for signs of noise interference, such as 'snow' or fines', general picture quality, and proper operation of the camera tilt mechanism and controller.

- Using the camera pan control, pan the camera fully left and fully right. During this step, check the video monitor for signs of noise interference, such as 'snow' or Sines', general picture quality, and proper operation of the camera pan mechanism and controller.

- Operate the camera's iris from a fully open to fully closed position. Check that it moves fully and smoothly between both positions. Finely tune the null adjustment control, if available, to reduce iris creep in either direction.

- Briefly (5-10 seconds) turn power on to the lighting system to confirm the operation of each of the lighting units.

In completing the checkout of the camera and lighting systems, check each system for damage to its wiring or connectors. Pay special attention to the tightness and general integrity of each connection. Check the video monitor connections and display to be sure of quality and integrity. Survey the dive station and neatly bundle all wiring. Route each wiring bundle in a manner which will lessen the chance of accidental entanglement during operations.

Check that all brackets, wires, and fasteners are fastened securely to the vehicle. Check the correct attachment of the umbilical to the ROV, by way of a strain-transferring shackle, such that any stress applied to the umbilical is transferred to a solid connection point on the ROV. This connection point should be far enough ahead of the actual umbilical connection to leave the connection stress-free in all patterns of umbilical movement.

If the vehicle, or any of its subsystems, has a leak detection circuit, turn on the circuit before launching the ROV.

2.5.5. ROV Operations

Divide ROV operations into the launch, operation, and recovery phases. Before beginning operations, review the mission plan for the ROV with all ROV operations personnel. Each person having some level of responsibility for a face of the operation should verbally demonstrate his knowledge of that responsibility to the ROV supervisor. The ROV pilot and the maintenance technician responsible for tending the ROV should carefully discuss their method of interaction and communication required for the mission.

In launching the vehicle, take the following steps:

- Lower the vehicle by an appropriate means smoothly and evenly into the water, avoiding any harsh contact with walls, railings, etc. If the vehicle is of the small inspection variety which does not have a tether management system (TMS), pay out the umbilical carefully during launch, to be sure that it does not become fouled or damaged. Pay particular attention to any 90 corners over which the umbilical must travel, and exercise caution to avoid unnecessary wear and abrasion.

- Perform an in-water systems checkout immediately before beginning the mission operations. This should include turning power on to the lighting systems, and operating the camera and thrusters to verify their correct operation.

- If the ROV is deployed into a body of water where a significant thermal differential exists between the air and water temperatures, allow the ROV to achieve thermal equilibrium before leaving the surface, or beginning operations. This should take 15-20 minutes, and lessens the stress induced on system pressure hulls. It also helps achieve greater accuracy for the depth sensing pressure transducer.

- Perform any necessary calibration of instruments or onboard systems required to support mission operations.

- If the ROV is being used in radioactive or contaminated water, the pilot should exercise caution in initially submerging the vehicle. A full downward throttle will cause the ROV's vertical thruster to spray water straight up, similar to a 'whale spout', as it submerges.

ROV operations will vary according to the specific mission goals, however the following considerations generally apply

- The pilot should always strive to choose the most logical route in guiding the ROV in travel during operations. He should choose and use underwater landmarks where appropriate.

- He should continually assess the potential consequences which might arise from guiding the ROV into each mission area. Particularly, he should remain aware of changes in the relative position of the ROV umbilical brought about by his operation of the vehicle. He should be especially aware of the umbilical position as it relates to underwater structures.

- The pilot should maintain an awareness of both vehicle position and the information relayed by its onboard sensory systems, such as depth and radiation dosimetry.

- The maintenance technician responsible for tending the ROV should remain aware of the amount of umbilical deployed in the water. Do not keep the umbilical taut, yet do not deploy an unnecessary amount of slack, either. The umbilical tender is responsible for maintaining the relation between the length of umbilical deployed and ROV distance from dive station.

The recovery of the ROV is the final in-water step in ROV mission operations. In general, the steps to recovery are simple and straightforward, as follows:

- The pilot should announce to all topside operations personnel that the ROV mission has been completed and to prepare for recovery of the vehicle.

- Begin the recovery of the ROV by recovering any available slack in the umbilical. If ROV operations have taken place in a radioactive pool area, a supply of low-pressure demineralized water must be available to rinse the umbilical and ROV as they leave the pool, before they are brought on deck. This will allow the rinse water to return directly to the pool. Wipe off excess rinse water, and carefully recoil the umbilical in its appropriate place on deck.

- The pilot should execute a 180- turn at the last work site and proceed to follow the umbilical back to the surface. Gently recover the umbilical ahead of the returning ROV. The pilot should issue any commands to the umbilical tender necessary to direct the recovery of the umbilical.

- Once on the surface, tow the ROV carefully via its umbilical, to the point-of-entry, and recover in the same manner as deployed. If used in a radioactive pool area, the surface of the vehicle, and any cavities, should be rinsed thoroughly with demineralized water and wiped off on deck. HI) personnel should perform a detailed survey of the ROV and it's umbilical, to assess any level of radioactive contamination present.

2.5.6. Post-Dive Maintenance

After ROV operations are finished, or if there is to be a long interim period before the next dive, conduct post-dive maintenance procedures in accordance with the following minimum levels of activity:

- Turn off all power supply switches to component systems, and secure the power supply.

- Disconnect all cabling and check each cable and connector for wear or abrasion. Spray connectors with some type of moisture displacement/ preservative compound.

- If the ROV is an inspection vehicle used for primary system inspection, store the umbilical in a plastic bag and seal.

- Check the camera, lighting, and thruster systems for signs of leakage, damage, or loosening of electrical connections. If there are any signs of leak into a pressure hull, take extreme caution in disassembling the component. There may be an increased internal pressure which could cause the component to explode upon opening. Follow individual manufacturers recommendations in this instance. Assume that the pressure hull may contain contaminated water, and take any necessary precautions accordingly.

- Check all O-rings for damage and re-lubricate with a coating of silicone grease before reinstalling .

- Clean all areas of surface corrosion, dry, and apply a light coat of silicone grease to the area. This is an interim measure to prevent further corrosion. It is not intended as a substitute for proper refinishing of the component area.

- Tag the ROV and all components as inspected and in proper operating condition. Be sure that they are in conformance with all in-house standards for such items. The tagging should also include the date of inspection and the name of the inspector. Move the units together to their designated storage area and log in.

Chapter 3

Underwater Operations

3. UNDERWATER OPERATIONS

This Chapter deals with a presentation of general underwater operations which are performed by divers or ROV's, in supporting maintenance requirements which arise at power plants. The following sections cover such topics as underwater cleaning, metal cutting, and welding operations, and include a general introduction to each, an overview of the equipment required to support those operations, and general guidelines covering the performance of each work task.

3.1. Vacuuming

3.1.1. Introduction

Underwater vacuuming is a technique typically used to clean debris, sediment, and other foreign matter from primary system pool areas. The process is based upon the use of a motor-driven, high-flow rate pump. The pump moves water from the pool through a filter system, returning the water directly to the pool or delivering it to the plants' own pool filtration system intake.

The diver vacuums by manipulating a suction hose attached to the inlet side of the pump. A vacuum suction hose can be attached to an ROV, as well. Several types of materials can be vacuumed, occurring in a variety of places, such as:

- Collection of the various particulate matter which may fall upon the surface of the pool and sink, gathering as sediment on the horizontal surfaces of submerged objects and on the pool bottom.

- Debris generated from in-water maintenance or construction activities, such as underwater metal cutting or grinding, where the dross resulting from the cut metal falls to the bottom of the pool.

- Elements of fuel bundles and other items being transferred in the pools, which become disengaged, such as nuts, bolts, and other fasteners.

Vacuum either after the fact, in terms of particulate accumulation, or in real-time, by placing a vacuum suction hose end close to an operation which creates a significant amount of waste material. In some instances, it may be more effective to control the waste matter as it is being produced while it may be more effective at other times to complete the scope of work before undertaking a thorough clean-up of the area. Where the waste material generated is small in quantity, the former method is most effective. Larger amounts of waste production favor the latter alternative.

3.1.2. Equipment

A typical system used for underwater vacuuming generally consists of the following pieces of equipment configured in a fully submersible package:

- Suction pump

- Drive motor

- Intake filter and strainer assembly
- Intake hose and guide handle
- Discharge hose
- Fittings

The suction pump should be of an appropriate type with a minimum 2" intake diameter. This allows the pump to achieve the rate of flow necessary for effective pool cleaning and filtration. This flow rate should be a minimum of 80-100 gpm.

The motor used should be large enough to power the pump and drive the filtration systems adequately. If electric, connect it to ground fault interruption circuitry. Some contractors have found 440v/3-phase motors in the 5hp range, to present a practical approach to this particular application. Other acceptable approaches use air or hydraulic drive motors. When using a hydraulic drive, be sure that the hydraulic fluid used is a water-based type, and fully compatible with pool chemistry. Additionally, use positive flow shut-off, quick disconnects on the submerged fittings, to prevent discharge of the fluid into the pool, in the event of accidental disconnection of the hose.

The submersible intake filter should be of stainless steel construction, as should the filter element and the strainer assembly. Filter elements may vary in size from 2-60 microns, according to individual requirements. Construct the filter housing so that a diver, using a pair of tongs, can safety release a full filter from the housing and replace it with a new filter.

The intake hose should be a minimum 2" internal diameter, non-collapsible, polyethylene suction hose. Use any length appropriate to the workscope, however, multiple shorter lengths in the 25' range are desirable, for ease of handling and decontamination. Attach a handling guide, constructed from aluminum or stainless steel, to the suction end of the hose. This will help the diver safely manipulate the suction end during vacuuming operations, while maintaining a safe operating distance from the vacuumed material.

The discharge port should be a minimum 2 1/8" opening, discharging directly to the pool. It should be fitted with a short length of polyethylene hose to provide some degree of back pressure to the pump. This will reduce the potential for pump cavitation during operations. Secure the end of the hose to prevent its whipping around when in use. In some cases, it may be desirable to use enough hose to reach a pool suction inlet in the pool filtration system. The filter containers should be equipped with aluminum quick-disconnect fittings, with the ears equipped with rings, allowing the use of extension tools to disconnect the fitting during filter changing operations.

If an electric motor is used, have an electrician test the unit to determine whether any electrical shorts exist. If a hydraulic motor is used, operate it on deck sufficiently to determine whether there is any leakage of hydraulic fluid from the system.

3.1.3. Guidelines

Review the proposed workscope to determine the approximate length of suction hose required to allow the diver unrestricted access to all areas in the vacuuming plan.

Determine whether to pump the discharge directly back into the pool, or direct it to a pool filtration suction inlet. If the latter option is selected, connect enough discharge hose to the filter discharge, before submersion of the unit, to reach the inlet. Identify a means of securing the discharge hose end close to the inlet.

Determine the acceptable radiation level for the filter, and monitor the radiation level of the vacuum filter using a remote-reading survey probe or periodic inspection with a submersible survey probe. A remote-reading survey probe is preferable, due to its non-interference with the diving and vacuuming operations. If this option is selected, confirm that the remote-reading dosimeter is properly installed at the filter before submergence of the unit.

Install the filter assemblies inside the filter container. Confirm that the filtration size specified (e.g. 6 micron) is in fact the filter in use, and that enough spare filters are available for replacement, should the initial filter become full.

Discuss the vacuuming areas and the dive plan with both the diving supervisor and the diver, to insure that each fully understands the intent of the maintenance action, the area to be vacuumed, and the proper handling and operation of the vacuum equipment.

Perform a current pool radiation survey and compare to the previous survey to confirm radiation levels and locations in the pool.

Lower the equipment into the pool deep enough to completely flood the suction hose and pump. Supply power to the drive motor temporarily, to operate the equipment, and check for leaks or ground faults, according to the type of system. Secure the system operation and proceed with the of diving and vacuuming operations.

Establish a clean base, or area from which to begin vacuuming operations, and from which the diver may continue to work. Do this by one of two methods:

- Attach a suction hose end to an extension tube so that surface personnel may initially clean an area on bottom from which the diver can begin.

- Where possible, the diver may clean a base from which to work, from an area above the work site, such as a stage or grating.

Underwater vacuuming is performed much as it is on the surface. However, underwater, it is important to set up several visual reference points to which to orient the vacuuming in a given area. This is important because the layer of material to be vacuumed may be very thin, and difficult to observe readily. It is also important to vacuum with a slow, deliberate motion, to avoid disturbing or stirring up the material more than necessary.

Monitor both the dosimetry of the diver and the vacuum filter regularly. Also, check the suction opening of the intake hose from time to time.

As the diver completes areas of the pool, update the map developed for the scope of work to reflect the work accomplished.

When the filter requires changing, as indicated by reduced suction and effectiveness on the intake hose, secure the vacuuming system and instruct the diver to change the filter. This operation requires that the diver use an appropriate set of tongs to open the filter container, secure the filter bag opening, and transfer the full filter bag to a submerged container specified by HP personnel. The diver will then install another bag in the container, secure the filter container, and resume vacuuming operations.

Upon completion of the planned vacuuming operations, secure the equipment operation and instruct the diver to confirm that the equipment is not fouled, and is ready to leave the water. Once the diver is safely on deck, remove the equipment from the pool, following decontamination procedures as instructed by HP personnel. Only after all the equipment has been completely retrieved to the surface, should the diver be dismissed from the dive station.

3.2. Mechanical Cleaning

3.2.1. Introduction

Most often, mechanical abrasion is performed by motor-driven revolving wire brushes. Of these, the wire disc and wire cup brushes are most common. These brushes are normally driven by hydraulic or pneumatic power sources. Wire brushes produce a bright finish on metal on which they are used. Only new brushes should be used on stainless steel, as brushes which have been previously used on carbon steel will induce corrosion if subsequently used on stainless surfaces. This also applies to grinding wheels and burrs used in underwater cleaning. They are quite effective in confined areas which would be otherwise difficult to access, such as with high-pressure waterblasting equipment.

3.2.2. Equipment

The equipment required for mechanical cleaning falls into four categories:

- Brushes
- Drive Motor
- Supply Hose(s)
- Power Source

These brushes are either revolving metal discs or cups, with twisted wire brush bristles fixed around their circumference. The disc brush is suited to very precise cleaning, such as weld beads and material cracks, and for photographic preparation. The cup brush is suited to the general cleaning of larger areas. In both cases, the stiff metal bristles are about 1"-1 1/4" in length.

The drive motor is most often a conventional multi-purpose handheld grinder, used to power a variety of tools. It can be either hydraulic or pneumatic, consisting of inlet and exhaust ports, a lever-type trigger assembly, a right-angle auxiliary handle for improved operator control, and a shaft drive fitting to which the brushes are attached.

The supply hoses, depending upon whether hydraulic or pneumatic, can be either rubber-clad, steel-braid hydraulic hose, or conventional 3/4" Chicago-Pneumatic type pneumatic hose. It has been reported that hoses used in radioactive environments have evidenced degradation from exposure to high radioactive fields. Such hoses should be inspected and tested regularly.

The hydraulic power source is a conventional hydraulic power unit, such as used in most hydraulic tool packages. It should be capable of delivering a minimum 7-9 gpm rate of flow, at 1000-2000 psi. Overhaul the system thoroughly and remove all non-compatible lubricants, if the unit is to be used in the radioactive pool areas. Replace the standard hydraulic fluid with a compatible mixture, such as ethylene-glycol, mineral oil, or demineralized water. The pneumatic unit will be a low-medium pressure, high-volume air compressor. It should be capable of delivering a minimum of 40 cfm, at 90 psi over bottom pressure.

3.2.3. Procedure

In using underwater mechanical wirebrushing equipment, as with operating any handheld power tools, take care that items, such as tool lanyards, are not accidentally caught by the rotating brush.

Depending upon the application, the tool or umbilical may require some form of additional flotation to assist the diver in the management of the tool system underwater. Make small items, such as a hand grinder, neutrally-buoyant by the attaching small float to its umbilical, a short length removed from the tool.

Because the diver will require the use of both hands to safely and effectively manipulate the tool, some type of work platform may be required to position the diver at the worksite. Cleaning a large area requires a reference system which will enable the diver to determine the extent of his progress and location. To support this requirement, develop some type of area grid marker or perimeter definition system. As with all underwater work accomplished in several stages, try to complete the area cleaning in a logically-sequential progression of effort. This will result in increased productivity through a reduction in the changeover times required. Each new diver or ROV operator needs to assess the previous level of work completed before continuing with the work.

3.3. Water Jet Cleaning and Cutting

3.3.1. Introduction

Water-jet methods involve generation of a stream of high-pressure water that is conveyed by hose to a gun or wand aimed at the workpiece in the area to be cleaned, cut or gouged. Pumps capable of producing pressures of 10,000 to 60,000 psi are used to intensify low-pressure water input sources. The process relies on forced erosion of the workpiece by the frictional forces imposed from the water jet. Gun and wand nozzles are individually designed for specific applications to maximize performance. The effectiveness and speed of cutting operations can be enhanced by adding abrasive particles [grit entrainment] to the water stream. However, grit entrainment may not be appropriate for use in the primary system environment.

Cleaning operations can be improved by inducing fluid caviation at the nozzle. Material composition generally does not affect the process. This process is also referred to as hydrolasing or waterblasting where the process is used at the lower end of the pressure range for cleaning or decontamination applications. It is extremely quick and effective in removing embedded matter from metallic surfaces, although they typically do not provide a bright metal finish. The gun is equipped with a nozzle which provides a specific spray pattern. The nozzle is located at the end of a slender tube so that it can reach into areas of limited access. This allows it to reach areas such as corners and irregular joints, which a grinding wheel could not easily access. This spray pattern may be in the form of a specific size or a shape pattern. Pattern size is measured in degrees, while shapes are described as cones or fans. Fan nozzle patterns are useful for broad cleaning of a surface. Conical nozzle patterns are useful for concentrated local areas.

In primary system applications within the nuclear environment, waterblasting is the preferred manner by which to clean and decontaminate underwater components such as flange faces. In general, waterblasting of surfaces in radioactively contaminated water areas is done using some type of remote method, and not by diver's using a handheld waterblasting gun. This is due to the increased potential for the diver to pick-up a radioactive particle which has been dislodged by the cleaning process. In the secondary system, waterblasting can prove to be equally effective. It is useful in the removal of marine growth from various structures, such as the circulating water intake components. Here, the diver using a handheld unit, can be extremely effective in performing underwater cleaning operations.

3.3.2. Equipment

The equipment requirements for a waterblasting system include the following major pieces of equipment:

- Waterblaster gun and nozzle
- Supply hose
- Abrasives Injection
- Pump/power supply

The gun, itself, usually consists of a 'T'-tube with a water supply and trigger assembly on the short leg of the 'T'. The nozzle is located on one end of the 'T' top, with a back-pressure nozzle located on the opposite end of the top. Water-jet nozzles are typically formed using a sapphire orifice. Orifices used for cutting range from 0.003 to 0.020 in. in diameter. Orifices used for general cleaning at lower pressures utilize greater diameters. Service life for a water-only orifice is 250 to 500 hours, depending on the operating parameters. The purpose of the back-pressure nozzle and 'T' arrangement is to provide an equal yet opposing force to the water directed from the working nozzle. This reduces the effort required to control the gun in operation. The top of the 'T' arrangement, or length of the gun, is about 42 inches in most cases. Nozzles of various sizes and patterns are interchanged at the working end of the gun tip.

The supply hose is a standard, high-pressure steel-reinforced water hose capable of sustaining the pressure requirements of the particular pump employed. Hoses have been developed for safe operation at pressures up to 36,000 psi. Operations conducted at higher pressures are not normally accomplished in a manual mode.

Abrasive material is often added or injected to the water-jet to enhance the effectiveness of the process where cutting thick materials is the primary objective. Precise control of the abrasive flow rate is key to a successful operation and is difficult to achieve. The controlling instrumentation is usually proprietary to the respective vendor. The major difference between surface and underwater abrasive water-jet operations is the requirement for a pressurized abrasive injection system for underwater operations.

The pump and power supply are normally configured together, in a single unit. The high pressures are generated by means of driving a fluid-pressure intensifier with a hydraulic-oil operated, positive displacement, piston-typed, double-acting reciprocating pumps. The intensifiers are available with pressure intensification ratios from 4 1 to 20:1 that provide outlet pressures approximating 10,000 to 60,000 psi. Common water jet cutting pumps operate in the 25,000 to 45,000 psi range. Common waterblasters operate in the 10,000-20,000 psi range. The hydraulic pumps used to operate the intensifier typically provide output flows and pressures of greater than 20 gpm @ 2750 psi. Hydraulic pumps are driven with electric motors or diesel engines in the 25 to 75 nominal bhp range, and require a Low Pressure (LP) water supply source.

In primary system usage, an adequate supply of LP demineralized water for this purpose is required.

HIGH PRESSURE WATER-JET OPERATING PARAMETERS
Figure 3-1

Intensification Ratio		Operating Pressure		Pumped Fluid Flow	
Nominal	**Actual**	**Nominal**	**Actual @ 2750 psi (18.7 Mpa) Oil Pressure**	**Per Stroke**	**At Rating**
4:1	4.211:1	12,000 psi (81.6 MPa)	11,580 psi (78.8 MPa)	0.05 gallons (0.189 liters)	5.0 gallons (18.9 liters)
10:1	9.992:1	30.000 psi 204 MPa)	27.478 psi (186.9 MPa)	0.02 gallons (0.076 liters)	2.0 gallons (7.6 liters)
13:1	13.151:1	40.000 psi (272 MPa)	36.165 psi (246 MPa)	0.015 gallons (0.057 liters)	1.5 gallons (5.7 liters)
20.1	19.846:1	65.000 psi (374 MPa)	64.676 psi (371 MPa)	0.01 gallons (0.038 liters)	1.0 gallons (3.8 liters)

Note: Pumped fluid flow at specified ratings are based on an intensifier stroke rate of 100 strokes per minute. Higher stroke rates may reduce seal life.

3.3.3. Procedure

As with other forms of underwater cleaning, the diver cleaning larger areas must have a visual frame of reference with which to measure his progress. Depending upon the material to being cleaned, the waterblasting may impair visibility in that local area underwater. In primary side operations, waterblasting may also impair the ability of surface personnel to monitor the actions of the diver at the work site.

In performing cleaning operations, determine a starting point for the area to be cleaned, and manipulate the waterblaster in a back-and-forth manner. The diver should maintain a distance of about one inch from the working tip, to the surface to be cleaned. In this fashion, the cleaned area is slowly enlarged.

Give special attention to the waterblasters' rear discharge jet, which is normally protected by a shroud. Make sure that it is securely fastened. Serious injury to the diver could easily occur in normal use if the protective shroud is lost or removed.

3.4. Mechanical Metal-Cutting

3.4.1. Introduction

Mechanical cutting is one method used to cut metal objects underwater. It involves the use of an underwater saw blade, abrasive wheel, or burr, which is most often driven by a hydraulic or pneumatic power tool. Only new blades should be used on stainless steel, as blades which have been previously used on carbon steel will induce corrosion if subsequently used on stainless surfaces. This also applies to grinding wheels and burrs used in underwater metal-cutting.

Examples of different tool requirements for mechanical underwater cutting vary according to the location of the material to be cut. Requirements in the spent fuel pool, for example, might include spent fuel rack changes. Another common requirement for metal-cutting is in the removal of various temporary brackets and bracing required during plant construction operations.

3.4.2. Equipment

Several different types of equipment are used underwater, to accommodate individual cutting requirements. Typically, the motive force supplied is either a pneumatic or hydraulic system. Where the cutting location is in a primary side pool, and the drive system is hydraulic, a compatible hydraulic fluid and aluminum positive-sealing quick-disconnect fittings must be used. This precaution will maintain pool chemistry, in case of a hose joint separation at the fittings, by not allowing hydraulic fluid contained in the hoses to flow freely into the pool. As previously mentioned, it has been reported that hoses used in radioactive environments have evidenced degradation from exposure to high radioactive fields. Such hoses should be inspected and tested regularly. In this guide, we shall consider the following types of equipment:

- Band saw
- Reciprocating saw
- Right-angle abrasive wheel

- Guillotine saw
- Tungsten-carbide burrs

Band saws are designed to cut various types of materials quickly and evenly, and produce a fine cut. The cut edges require little finishing. The type most often used by divers can accommodate materials up to 3 1/2 inches in diameter, or a 3 1/2 inch x 4 1/8 inch rectangle. The saw is light in weight and easily managed by the diver. It is extremely versatile and suitable for a range of different cutting applications.

Reciprocating saws are designed for cutting through the plane of a large object, such as a steel plate, where access is available only from one side. Additionally, they are useful in areas where access is restricted by physical obstructions. Thickness of the cut material is limited only by the blade length, minus the length of the reciprocating stroke. The length of the proposed cut is unlimited, due to the configuration of the saw.

In general, material up to 16 inches in thickness can be successfully cut. However, remember that as overall material thickness increases, so does the friction effect on the sides of the cutting blade. This increases the chance of the saw 'binding' or 'seizing' during cutting operations. It also places a increased power requirement on the drive motor.

A second common problem associated with these types of saws is that their blade is supported only at its attachment point to the saw. This factor allows the saw blade some flexibility and freedom of motion, which can result in a cut edge which is both somewhat rough and uneven.

Right-angle abrasive cutting wheels are designed for the quick removal of protruding metal objects flush with a flat surface. The abrasive cutting wheel is self-consuming, that is, as cutting operations progress, the wheel diameter decreases. This type of system allows for the use of different types of abrasive wheel materials for differing applications. However, it will result in the creation of excess waste material in the water, in addition to the dross resulting from the cut metal. The radius of the wheel, minus the radius of the arbor [shaft] of the saw, determines the maximum cutting depth. Abrasive wheels range up to 10 inches in diameter, with the most common sizes for underwater work being in the 6" - 8" range. This cutting systems is easily managed by the diver, and produces an exceptionally smooth cut. It is well suited to cutting angle-members, brackets, bracing, and small rods or tubulars.

Guillotine saws are designed for the mechanical cutting of larger pipe or tubulars. This saw uses a reciprocating blade attached to both sides of an inverted 'U'-shaped frame, attached around the tubular. As the blade moves from side to side, the operator mechanically advances the blade along the 'U', through the tubular. This is done using a simple hand crank and gear assembly. Guillotine saws are manufactured in different sizes, and each size is capable of cutting a range of tubular sizes. Most commonly, they begin with a 12 inch saw, and increase in size to 36 inches. Properly mounted, their main advantage is their provision of a smooth, square cut perpendicular to the tubular.

The most noteworthy problem associated with guillotine saws is in their inefficient power transfer. If the tubular to be cut has any amount of rotational stress built up in it, as the cutting progresses, the tubular will begin to roll. When this occurs, there is a good chance that the blade will 'seize' and break in the cut. While this is true to some degree with both the band saw and the reciprocating saw, it is most likely to occur in using the guillotine saw.

Tungsten-carbide burrs are used in underwater welding and other operations. They are usually fitted to a hand grinder, such as a pneumatic pencil-type grinder. Burrs come in a variety of sizes and shapes, according to the specific type of application required. They are quite effective in work requiring precise, dressed cuts over a limited area.

3.4.3. Procedure

Determine whether to allow dross from the metal cutting to fall to the bottom, or to retrieve it to the surface. If work is to be done in a radioactive setting, collect the dross with a vacuuming system [see Underwater Vacuuming] at each work site, while each cutting operation is being done. In pool areas, develop a provision for handling large or angular objects to be cut. This will prevent their dropping free and damaging the pool liner or flooring.

Confirm that the contractor has the necessary equipment onsite for each task. Be sure to configure the equipment and test in operation before using. In addition, also confirm that the

- blade installed in the equipment is new and properly installed. Be sure that adequate replacements are available at the dive station.
- power source supplying the equipment is fully ready. If a hydraulic system is used, run the equipment on deck sufficiently to determine whether there is any leakage of hydraulic fluid from the system.
- equipment has enough hose attached to allow the diver unrestricted access to all areas within the scope of work.
- underwater cutting system has a positive on-off switch located on the surface, at the dive station, and also on the equipment itself.
- lubricants, if any, used on the equipment meet all plant specifications for compatibility.

Before the diver enters the water, discuss the planned work with the diver and the diving supervisor to confirm their understanding of the work tasks, their exact location, and the proper operation of the equipment used. When the work is to be done in a radioactive environment, a second pool radiation survey is suggested to confirm the radiation levels found in the preliminary survey. Do this at each of the divers' work sites.

After completing these items, direct the diving supervisor to proceed with the diving operations. Begin by lowering the equipment into the water. The diver can then enter the water and guide the equipment to the work site. In pool areas, lower the equipment without power to the units. Take care not to move equipment over the stored fuel at any time.

The diver should describe each object and its exact location, to the diving supervisor, before beginning cutting operations. The diver should perform measurements required for exact placement of the cut, and relay them to the diving supervisor for confirmation. If required, the diver should also position the vacuum's intake close to the cut, to collect the dross as it is formed.

The diver will first position the equipment at the mark to begin the cutting. The power for the equipment and vacuum will then be turned 'on'. He should then inform the diving supervisor as he begins the cutting operation. He should inform the diving supervisor of the saw's progress, and again, upon completion of the cut. In pool areas, the diver will secure power to the equipment immediately upon completion of the cut.

If the saw blade, abrasive wheel, or burr, should break or become dull while in the pool area, the diver should request a replacement blade and repair tools. This will allow the diver to make the blade repair underwater. This may be important if the blade has become radioactively contaminated in use. The defective blade should be removed and placed in a suitable container designated by HP personnel. In non-contaminated water, and particularly where visibility is poor, bring the equipment to the surface for repairs.

The diver should reposition the equipment and vacuum as necessary, after each cut is made. The diver should also report each piece of metal as it is cut, to the diving supervisor, so that he can record the disposition of the material.

Upon completion of the last cut, secure the power to the equipment. The diver should then ready all equipment used during the dive to come to the surface. The diver should monitor each piece of equipment as it is recovered from the work site, before he surfaces. After all equipment has been recovered, the diver should inform the diving supervisor of his intent to surface. The diving supervisor will then oversee the divers' ascent.

3.5. Oxy-Arc Metal Cutting

3.5.1. Introduction

Oxy-arc metal cutting is the process by which high-amperage, direct-current is sent from a surface power source, down a cable, to a special underwater torch head. This head is specially designed to conduct both electric current and oxygen to a tubular mild-steel burning rod placed in its head. The oxygen is conducted to the torch by a hose attached to the power cable. It, then, passes through a center bore in the cutting electrode [rod], and out the tip.

An electric arc forms when the rod tip is touches the grounded metal to be cut. This provides the concentrated heat source necessary to melt the metal in a very localized area. The high pressure gas directed through the hollow rod displaces the molten metal, forming the kerf, or cut. Oxygen is the gas of choice, hence the name "Oxy-arc", because it reacts with the ferrous metals, creating an exothermic reaction. This reaction intensifies the cutting action of the process.

By following strict safety procedures and guidelines, the diver can safely use this technique to quickly and efficiently cut metal up to several inches in thickness. This cutting process results in a kerf about 1/4 inch in width, with an extremely rough edge, compared to sawn edges. The obvious advantage to this method is the speed with which metal is cut. This makes it ideal for salvage applications. Disadvantages include the disruption of pool chemistry in plant pools, and possible contamination of the nuclear fuel.

This cutting process is very operator-sensitive. Speed, smoothness, and penetration of the cut, all depend upon the operators experience and skill. Areas of potential use at nuclear plants might be in repair tasks or changes to the circulating water system intakes and piping structures.

3.5.2. Equipment

Underwater oxy-arc cutting requires several pieces of specialized equipment, which must be assembled and used only by trained personnel. The basic underwater cutting equipment group consists of

- Power source
- Welding cables
- Safety switch
- Oxygen supply
- Electrodes
- Arc-oxygen cutting torch

The power source required to support underwater oxy-arc cutting operations must be capable of providing a minimum of 300 amperes of continuous direct-current to the torch head. The source normally used to meet this requirement is a standard D.C. welding machine, in the 300-400 amp range. For most underwater cutting applications, a machine setting of straight polarity produces the most desirable results.

The welding cable recommended for underwater oxy-arc cutting operations is size 2/0 or larger extra-flexible welding cable. Size 2/0 provides better performance than size 1/0 over a greater distance from the power source. This is due to its lower resistance value. The extra-flexible lead is important to provide the diver with the maximum degree of comfort. This is necessary, since this operation requires a high degree of operator 'touch' and sensitivity.

Locate a positive-operating disconnect safety switch, compatible with the power source used, at a surface location in the secondary circuit. This switch is normally operated by the tender or diving supervisor, and serves to protect the diver from accidental electric shock. A knife switch is the switch type of choice for such operations. This provides the best protection, by having current supplied to the divers' torch head only when the diver is actually cutting.

The oxygen supply used for underwater oxy-arc cutting may be of any gaseous grade from welding to medical. Likewise, the delivery flow is not critical beyond certain general parameters. Secure the high pressure gas cylinders which store the gas to prevent their accidental fall. Locate them in an open environment to prevent a local accumulation of pure oxygen. Otherwise, this could represent a serious fire hazard. Equip the cylinders with an oxygen-clean high-pressure gas regulator. Where oxygen delivery pressures must exceed 180 psi to accomplish the work task, a high- pressure high-flow regulator produces best results.

There are many underwater cutting electrodes [rods] available. Most common are 5/16" x 14" mild-steel rods with a 1/8" center bore. These rods are also available with a variety of surface coatings, or flux. The type of flux used gives each rod a unique character in performance. Another type of rod is a purely exothermic design. It uses a thin-wall 5/16" rod whose core is made up of a bundle of small magnesium rods. Once ignited, the electric power source for this type of rod is no longer required.

The cutting torch head itself, consists of a handheld pistol grip assembly which includes an oxygen control valve (trigger) and collet-type rod holding mechanism. By unscrewing the collet retainer counterclockwise, the collet is allowed to expand, and the rod can be inserted. Screwing the collet retainer clockwise tightens the collet concentrically around the rod. This forms the positive electrical contact necessary for the arc process to occur. The inserted end of the rod seats against a rubber gasket with a hole in the center. This allows the oxygen to pass, when the trigger lever is depressed. Quite often, mounting a 1"-2" standoff on the collet retainer, acts as a positive guide to prevent the diver from burning the rod too far down. This prevents accidental damage to the torch head itself.

3.5.3. Procedure

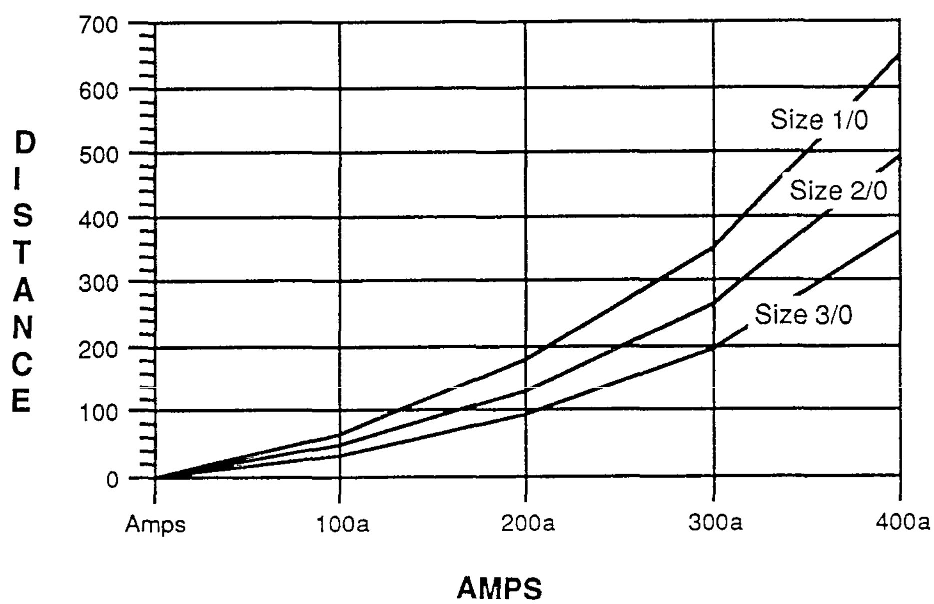
The process for underwater oxy-arc cutting operations is similar in progression to the process previously outlined for the various types of mechanical cutting. Refer to those sections as general references, with the following exceptions:

When using a welding machine, ground the welding machine frame. If using a welding generator, be sure that neither terminal is bonded to the frame. Securely fasten all electrical connections.

In connecting the cutting leads to the power source, connect the electrode holder to the negative terminal, and the ground lead to the positive terminal. To determine proper [straight] polarity for underwater cutting, assuming that the markings on the machine used may be absent, take the following steps:

- Turn off the power source completely and discharge if necessary
- Connect both the ground and power leads to the terminals on the machine
- Clamp an electrode to the ground lead. Insert another electrode into the torch head and place the tips of both electrodes in an electrolytic solution, such as salt water.
- Make sure the container is properly insulated, and placing the tips of the electrodes 1"-2" apart, apply current from the power source.
- The polarity is correct if bubbles flow from the negative electrode in the torch head. Almost none will flow from the positive electrode. If the opposite case occurs, turn off the power and reverse the leads to achieve the correct polarity.

In secondary side diving applications, where the length of the cutting lead may be more than 400' from the welding power source, use a single cable larger than 2/0, or parallel two or more cables of sufficient size to reduce the voltage drop. However, each additional cable and its connectors will increase the resistance. Compensate for this by increasing the output of the welding machines. This is accomplished by raising the open circuit voltage of the D.C. generator or, if a rectifier is used, by increasing the amperage setting. Voltage drops for single lengths of sizes 1/0, 2/0, and 3/0 cable are shown in Figure 3-2, in the following table:



VOLTAGE DROP/100 FT. CABLE
Figure 3-2

Properly insulate the power supply cable, from the welding source to the secondary circuit positive-disconnect switch. This will prevent any possibility of shorting out the switch. Locate the switch in such a position that the tender, or diving supervisor, can operate or oversee it's operation the entire time that the diver is below the surface. Further, no one shall operate the switch, opening or closing the circuit, unless specifically directed to do so by the diver. When so directed, he shall immediately confirm each change to the diver.

Determine the proper line pressure requirements for oxygen flow, from an oxygen gas regulator, using the following simple formula:

- PSIG = 1/2 Water Depth (ft) + Required Over-bottom Pressure

  Example: 3/4" steel plate to be cut in 62' feet of water:
  86 psig = (1/2 o 62) + 55 (from Figure 3-2)

Set the over bottom pressure with torch valve open, and with a rod inserted in the torch head. The diver should direct this operation before beginning the first cut. The gas regulator settings for oxygen pressures necessary to support various oxy-arc cutting requirements are shown in Figure 3-3, in the following table. Line friction has been taken into consideration for oxygen hose lengths up to 500' feet. Remember, oxygen delivery requirements greater than 180 psi require a high-flow oxygen regulator.

UNDERWATER OXY-ARC CUTTING
OXYGEN GAS REGULATOR SETTINGS
Figure 3-3

Wall Thickness	Over-bottom Pressure
less than 1/4"	35 - 40 psi
1/4"-3/8"	40 - 46 psi
3/8"-1/2"	45 - 50 psi
1/2"-3/4"	50 - 55 psi
3/4"-1"	55 - 60 psi
1"-1 1/4"	65 - 70 psi
1 1/4"-1 1/2"	75 - 80 psi
1 1/2"-1 3/4"	85 - 90 psi
1 3/4"-2"	95 - 100 psi

Store oxy-arc cutting rods in a moisture-free environment to preserve the condition of their flux coating. Perform a visual inspection of each rod before sending the rods to the diver for use. Be sure that

- the flux coating on the rod is firmly intact
- the center bore of the rod is free and clear of any obstruction which would prevent the flow of oxygen

Following are general techniques used in various underwater cutting operations.

General Techniques for Using Steel Tubular Insulated Electrodes
Begin by attaching the ground cable clamp to the piece of metal to be cut, as close to the intended cut as possible. Be careful that the piece of metal to which the ground lead is attached will not 'fall away' after the cut is completed. In certain circumstances, it may not always be possible to connect the grounding cable directly to, or next to, the piece to be cut. In those situations, the diver must be careful to remember that the electric current will flow in a straight line from the electrode arc to the grounding clamp position.

CAUTION
It is extremely important to plan any underwater operations involving electric arcs, such as arc-water gouging, wet welding, etc., so that the diver never comes between the grounding clamp and the electrode arc. Severe electric shock will result.

To start the cut, hold the electrode perpendicular to the metal surface to be cut, placing the tip of the electrode against the work. Open the oxygen valve at the torch head by depressing the trigger lever, and call "Make It Hot" to the topside switch operator. If necessary, withdraw the electrode slightly and tap against the grounded work surface to start the arc.

Advance the cut by dragging the electrode along the desired line of the cut, keeping it perpendicular to, or with the tip at a slightly leading angle towards the direction of travel. The tip of the electrode should contact the metal being cut with pressure exerted in two directions:

- inward, to maintain contact with the metal, and to compensate for electrode consumption.
- forward, in the direction of the cut.

Do not try to hold an arc length while cutting, as in the welding process. This will result in an inconsistent cut with several 'hangers'.

If an incomplete cut occurs due to some fault in manipulation or water turbulence, this will be indicated by a back flash as the broken arc is extinguished. This flash will be visible even in murky water. If this occurs, stop the advancement of the electrode, go back, and restart the arc in the cut, behind the point where the back flash occurred.

When the electrode has been consumed, or the diver desires to cease cutting, he should call out "Make It Cold". Adjustments may then be made, or the electrode changed. Always give this notification. The diver should maintain the torch in the cutting position until the tender acknowledges "Cold". This safety precaution is mandators regardless of the types of electrodes or current furnished.

Techniques for Cutting Thin Steel Plate

The technique for cutting metal less than 114" in thickness is slightly different from that used on thicker plate. Instead of maintaining the electrode tip in the cut, and pressing it against the lip of the advancing cut, the tip should barely contact the plate surface as it advances along the line of the cut. An alternate technique, where visibility is poor, is based on increasing the effective thickness of the plate being cut. Holding the electrode so it points away from the direction of the cut, inclined toward the plate at an angle of about 46 degrees, increases the effective thickness of the plate. This allows normal working pressure to be applied to the electrode.

Techniques for Piercing Holes in Steel Plate

Piercing a hole in steel is easily accomplished using the oxy-arc method. The procedure is rapid and the technique is as follows:

- Touch the electrode to the plate lightly at the desired point. The diver will then open the oxygen valve, calling "Make It Hot" to the topside switch operator.

- Hold the electrode stationary for a moment, then withdraw momentarily if necessary. This permits consumption of the steel tube back inside the flux covering.

- Insert the electrode slowly into the hole until the plate is completely pierced.

Using this method, piercing of a 3" thick steel plate can be done without excessive difficulty.

Techniques for Cutting Cast Iron Stainless Steel and Non-Ferrous Metals
Cast iron, stainless steel, and non-ferrous metals are not readily oxidized, so underwater cutting becomes essentially a melting process. No advantage is derived from the use of oxygen, except for the mechanical effect of blowing the molten metal from the cut. Compressed air is recommended as a substitute for oxygen when cutting these metals, as both a safety and cost-saving factor.

The "drag" technique used for cutting steel is also not satisfactory when cutting cast iron and non-ferrous metals. The operator must manipulate the tip of the electrode in and out of the cut since melting takes place only near the arc. For thin plates, manipulation of the electrode is not necessary and the operation is essentially the same as when cutting thin steel plates. For thicker pieces of metal, since the cutting action is dependent solely upon the melting action of the arc, all available current up to a maximum of 500 amperes should be used. Further, use all means of decreasing the current loss between the source and the torch head, such as

- confirming that all electrical connections in the secondary circuit are clean and tight.

- thoroughly waterproofing each of the in-water connections of the secondary circuit.

- securing the ground lead as close to, if not actually on, the piece of metal to be cut

- uncoiling the cutting leads on the surface, and arranging them in such a manner that portions of either lead do not overlap, as in a back-and-forth serpentine arrangement. This will prevent the formation of a local electric field which serves to raise inductance in the lead.

3.6. Exothermic Metal Cutting

3.6.1. Introduction

Exothermic cutting, as it applies to underwater services, chiefly refers to a process where an ignited material produces enough heat to cut metal and other materials with which it comes in contact. Combustion of the material is started using an electric current. The current is secured after the exothermic material has ignited. Often, the material requires an auxiliary oxygen source to maintain combustion. The two principal forms of exothermic cutting devices are

- exothermic underwater burning electrodes
- thermal lances

Exothermic underwater burning electrodes, such as the *Broco*® rod, were introduced some years ago. They are 5/16" O.D. thin-wall electrodes containing a small bundle of rods made from exothermic materials.

Thermal lances are sometimes referred to as burning bars. They come in various lengths up to 10' feet, and are about 1" in diameter. Like burning rods, oxygen passes through a center bore to the tip.

The principal advantage to the process is that the electric current is not needed to produce the heat necessary to cut the material. Therefore, the material need not be conductive to be cut efficiently.. This process is effective for wood, concrete, steel, and other material coatings or marine growth. Likewise, where a sustained high-amperage electric current is not desirable, exothermic cutting provides a viable solution. One of the chief advantages of this process is the sustained burning time provided by the length of the lance. Given an open work area with a great deal of rough cutting to be done, this is an excellent alternative.

3.6.2. Equipment

Both exothermic systems have equipment requirements similar to those detailed in the oxy-arc cutting subpart discussed elsewhere in this section. However, the thermal lance does not require a hand-held torch head, only an oxygen control valve. Further, exothermic systems can also be "ignited" using a 12vDC battery in lieu of a welding power supply source. Where the workpiece is not electrically conductive, a separate conductive strike or "scratch plate" can be used to initiate the exothermic reaction.

3.6.3. Procedure

Exothermic burning electrodes are used much in the same way as oxy-arc cutting electrodes. From an operational standpoint, the fact that electric current need not be maintained is the only difference. Exothermic rods produce a significantly larger amount of dross from the cut than do oxy-arc electrodes. They also produce a kerf about 1/2" in width. The cut edge produced by this process is quite rough, as one might imagine.

The thermal lance is ignited at the surface by application of direct heat to the hp. or at the work site, by electric current. The rod length and method of employment determine the length of time which the lance burns. As with the exothermic electrodes, the lance produces a very rough cut with large amounts of dross. It's kerf produced is about the width of the lance used.

In both processes, place the tip of the device against the material to be cut, and drag the burning tip along the line of the cut.

For materials too thick to be cut in a single pass, first pierce a hole in the material. Then, manipulate the tip of the device in a sawing motion the width of the material, in the direction of the line of the cut. This procedure is very similar to the gouging of thick material, which will be discussed in the next subpart on arc-water gouging.

> **NOTE**
>
> **Refer to the subpart on General Techniques for Using Steel Tubular Insulated Electrodes, located in the previous section covering oxy-arc cutting, for a discussion of safety issues related to the use of underwater electric arcs.**

3.7. Plasma Arc Cutting

3.7.1. Introduction

Plasma Arc Cutting (PAC) is an electro-thermal cutting process, in which a gas is ionized by the flow of current in a high intensity electric arc. Since the ionized gas is electrically conductive, current flows from the negative potential of the electrode, contained in the torch head to the positive potential of the metal. The electrically-charged gas is squeezed through a small orifice in the nozzle of the torch head, at a pressure of about 50 psi. This causes the heat energy of the arc to rise well above that of conventional oxygen/fuel cutting processes.

The higher temperatures, in excess of 30,000° F. coupled with the strong gas flow, quickly melts metal and blows it away. The plasma process requires no preheating, and with a properly matched power supply, is 3-5 times faster in cutting carbon steel than utilizing an oxygen/fuel process. Typical gases used in the PAC process include oxygen, air, nitrogen, or a mixture of argon/hydrogen.

Because it is an electrothermal process, it will cut any material that is electrically conductive. This makes it very desirable for both aluminum and stainless steels. For improved performance on these and other non-ferrous metals, use a gas such as nitrogen as the ionizing gas.

The application of this process to underwater work is now cutting-edge technology. PAC appears to be somewhat depth sensitive. However, cutting has been successfully performed at depths to 25' feet of water. Hyperbaric tests have been performed to depths of 66' feet of water. The process can result in little or no dross, when cutting thin metal. Stainless steel has been cut underwater up to 4 1/2" in thickness, using a 1000 amp power source and Argon/H_2 plasma gas.

3.7.2. Equipment

The equipment setup required for plasma arc cutting is simple, small, and self-contained. It consists of the following components:

- Torch head and work cable
- Gas, regulator, and filter
- Power supply

The torch head typically comes in two configurations, a standard hand torch and a machine [straight] head. The latter is intended for use with automated cutting systems, and is suitable for adaptation to ROV use.

Certain modifications to the torch head are required for use underwater. The internal components of the torch head are potted in a hard epoxy resin, to waterproof and insulate them. This prevents any chance of their contact with water. A rubber-type covering is substituted for the standard braided wire covering found on the torch lead. Many plasma arc cutting torches can be fitted with special accessories that enable them to gouge as well as cut. Current and control cables plus the cooling hoses that support the operation of the torch are generally bound together into a bundle and sheathed with some sort of waterproof or rubber-type covering. These cable/hose bundles are factory assembled in specific lengths. Distance and resulting cable/hose lengths between the torch head and power source are always minimized to reduce voltage drops and losses for both the main plasma arc and especially the high-frequency pilot arc.

A variety of gases including compressed air may be used depending upon the actual application. Base material, depth, and accuracy of the cutting or gouging operation will determine the actual gas or gases to be employed. Compressed gases for shielding and the plasma gas may include argon, carbon dioxide, helium, hydrogen, nitrogen or mixtures of these gases.

Although not specific, the following rule of thumb provides a good starting point for gas selection: (based on past operations)

- At shallow depths (< 20 ft) and thin material (<1 in.) argon, carbon-dioxide, nitrogen or compressed air either alone or in combination may be satisfactory.

- At moderate depths (20 to 40 ft) and thicknesses (1 to 2 in.es) argon,

- At greater depths (over 40 ft), irrespective of thickness, argon-helium or argon-hydrogen mixtures will probably be required.

The quality of the gas used is critical to the success of the process. Compressed air must be clean, dry, and oil-free. Compressed gas must be of high purity, such as the 99.995% purity requirement for nitrogen. Use a line filter if there is any doubt about quality of the gas. The filter should be capable of removing 99.99% of oil, water, and particulate matter down to 3 microns in size. Lower purity of the compressed gas, or leaks in the supply hose or connections, will result in the following occurrences:

- Decreased cutting speed.

- Deterioration of the quality of the cut.

- Decreased cutting thickness capability.

- Reduction in the life of the operating parts of the torch head.

Accurate control of the gas pressure to the torch head is necessary for best performance during cutting operations. The gas regulator must be capable of delivering gas at the specified minimum working pressure at the torch head. Gas delivery pressures at the torch head greater than specified will significantly shorten the life of torch parts. As with oxy-arc burning, the 90-120 psi delivery pressure range is meant to be an over-bottom pressure. As with oxy-arc underwater cutting, set the regulator while the torch head is at the work site, with gas flowing through the torch nozzle. Calculate the approximate over-bottom pressure using the following formula:

- OBP = (Water Depth ÷ 2) + 100

The power supply which supports the underwater plasma arc cutting process is generally 3-phase, whose output can vary from 100-600 amperes in range. Currently, machines in the 200 amp range are being tested for use by divers. Linking a 400 and 600 amp machine in series has produced successful underwater cutting at 1000 amps. Depending upon the exact type, power supply requirements can range from 208v 3-phase to 440v 3-phase.

3.7.3. Procedure

The process preceding plasma arc underwater cutting is similar to that for oxy-arc cutting operations. Refer to that section for a general discussion of underwater electric arc cutting, and the subpart in the previous section on 'Underwater Mechanical Cutting' for a complete discussion of the process.

Properly implemented, operations will produce clean cut surfaces and can be up to three to five times faster than comparable attempts with the oxy-fuel process on some materials. Since an arc must be established between the torch head and the conductive material to be cut, it is very important that the surface to be cut be made clean by some means. Failure to have a moderately clean surface prior to commencement of the operation may prevent proper arc initiation or cause erratic arcing and cutting.

One distinct advantage of the process is the directional and predictable flight of the dross. This enables capture, proper clean-up and disposal of the removed material from the kerf.

Disassemble and inspect the torch prior to each dive. Replace parts as necessary. All consumable parts on the torch generally require replacement after approximately 150 ignitions. The number of ignitions will vary greatly depending on the specific application.

Techniques are categorically similar for both manual and machine or remote operations. Machine operations have the advantage of consistent torch stand-off distances and travel speeds.

Due to the self-contained nature of an underwater plasma arc cutting or gouging system, set-up usually only involves connection of primary power (usually 3-phase, 240/440 volts), gas(es) supply and the torch/cable bundle assembly to the power source. As previously discussed, locate the power source as close to the work area or component to be cut as possible, to minimize torch cable bundle lengths. Set-up exactly as conducted in demonstration or qualification trials for the specific work scope, unless otherwise proven.
At a minimum, follow the manufacturers suggested safety guidelines, which should include the following points:

- Do not attempt the removal or repair of torch parts underwater

- The driver should be careful not to touch the grounding clamp or material being cut, while PAC is in operation.
- Install a positive disconnecting safety which in the secondary circuit which can be operated by topside personnel.
- The driver must never wrap the torch lead or ground cable around any part of himself, or let the torch, torch lead, or ground cable come in contact with his diving helmet while PAC is in operation.
- Wear only dry diving suits, with 2-3 pairs of latex gloves securely fastened, one over the other, on the divers' hands. This provides a significant level of redundancy in insulating the diver from the current.
- The diver should maintain a 'floating' electrical potential at all times, with no possibility of connection to a ground or power source.
- No one should touch the coiled torch leads while PAC is in operation.

Techniques for Cutting Stainless Steel Using Nitrogen
Attach the grounding clamp to the work site. Position the torch nozzle 1/16"-1/8" off the metal to be cut. Plan the cutting process to begin at an edge, rather than in the center of a piece of metal, thereby eliminating the need for piercing. Depress the torch start switch. After 2 seconds, the arc will form, and arc transfer to the work will occur if the nozzle is close enough to the metal.

Drag the torch head along the line of the proposed cut, just above the metal surface. The diver must determine the speed of travel. Dragging the torch head directly on the work will result in premature wear on the nozzle. Reduce the speed of travel if the diver reports sparks visible on the top side of the work.

Disassemble the torch head and check those consumable parts before each dive. Replace parts as necessary. As a rule, those parts will need replacement about every 150 ignitions.

General Techniques for Gouging
In the gouging process, a special gouging nozzle replaces the standard cutting nozzle. After installing the gouging nozzle, decrease the normal gas pressure by 20% for gouging.

Tilt the torch head 45° to the work surface and initiate the arc. Feed into the gouge along the lines of the cut. Multiple passes may be necessary to create progressively wider and deeper cuts.

Techniques for Piercing

Hold the torch at an angle to the work surface, pointing away from the diver, and initiate the arc. Roll the torch head slowly to a perpendicular position to the surface of the metal. When the piercing of the metal is complete, proceed with the cutting procedure.

> **NOTE**
> **Refer to the subpart on General Techniques for Using Steel Tubular Insulated Electrodes, located in the previous section covering oxy-arc cutting, for a discussion of safety issues related to the use of underwater electric arcs.**

3.8. Arc-Water Gouging

3.8.1. Introduction

Arc-water gouging is a process similar to conventional arc-air gouging performed on land. The exception is that water is pumped through the orifice alongside of the electrode instead of air, which displaces the molten metal. This process is very similar to oxy-arc cutting, discussed in detail elsewhere in this section. There are, however, two main distinctions between the two:

- Arc-water gouging uses carbon electrodes instead of the steel electrodes used in oxy-arc cutting.
- The arc-water gouge does not require oxygen as a component in the cutting process.

The process is inherently safer than oxy-arc cutting because oxygen is not used. This eliminates any chance of explosions resulting from pockets of trapped oxygen near the work site. The process produces a gouge about 1/4" in depth and free from slag. It is ready to weld, if necessary. The process is well suited to confined areas where oxygen-pocketing is a potential problem.

3.8.2. Equipment

The equipment required for arc-water gouging is similar to that required for oxy-arc cutting, with the following exceptions:

This torch head is designed to accommodate the water flow required for arc-water gouging. Some models can also serve as an underwater welding 'stinger', by replacing the collets with those designed especially for welding electrodes. Otherwise, the general configuration is very similar to that of an oxy-arc torch head.

Arc-water gouging requires a high-pressure water pump capable of delivering a minimum of 90 psi over-bottom pressure, with a minimum 3.5 gpm rate of flow.

The power source must be capable of delivering between 350v-450v D.C. to the torch head. Current levels below this capacity may not be effective. Figure 3-1, shown previously, provides a chart of line voltage drops per 100' of cable.

3.8.3. Procedure

The 9" carbon electrodes used for arc-water gouging are used in much the same manner as the 14" steel electrodes required for under cater oxy-arc cutting. In both cases, the electrode acts as a point of contact between the power source and the grounded work metal. This creates an electric arc which heats the metal to a molten state. The high-pressure stream of water which emerges from the torch serves to sweep away the molten metal from the gouged area. The electrode is slowly consumed by the process, according to the voltage used and method of employment.

To gouge, hold the torch at a 40° angle to the work. Progress along the line of cut fast enough to maintain an arc and desired depth of groove. To pierce a plate, hold the electrode at a 75° angle to prevent slag from blowing directly back at the diver. After piercing the plate, proceed to cut the metal with a sawing motion. Continuously move the tip of the electrode from the front of the plate to the back, inside the pierced hole, and in the direction of the line of cut. This will result in the steady washing away of metal, in effect cutting the metal along a line of cut.

NOTE

Refer to the subpart on General Techniques for Using Steel Tubular Insulated Electrodes, located in the previous section covering oxy-arc cutting, for a discussion of safety issues related to the use of underwater electric arcs.

3.9. Wet Welding

3.9.1. Introduction

Welding underwater can be performed with much the same degrees of quality and strength that are achievable in surface welding operations. Underwater, welds can be made in either a specially-designed dry habitat, or directly in the water, by trained diver-welders. Dry habitat welds, because of the increased pressure of the surrounding water at depth, are known as hyperbaric welds, to differentiate them from dry surface welds. Welding done directly in the water is simply known as underwater wet welding.

In the nuclear environment, the welded repair of highly radioactive metal components can present a significant maintenance problem. The natural shielding ability of water is used to protect the welding personnel. This helps to support plant ALARA goals, and makes underwater wet welding the production alternative of choice in many situations. In a non-radioactive nuclear environment, such as the intake structure, underwater wet welding may also prove to be more cost effective than other methods, for achieving a suitable level of repair.

Welding operations are accomplished using a welding procedure and welders tested and qualified to pertinent industry standards. Welds produced in this manner are said to be 'code' welds. Typically, code welds which are performed on the surface, are made according to either the American Welding Society (AWS) D1.1 or American Society of Mechanical Engineers (ASME) Section IX specifications for structural steel welds, and boiler and pressure vessel welds, respectively. Underwater wet welds are made in accordance to the AWS D3.6 specification. This specification addresses considerations unique to wet welding and the underwater environment.

Because the ASME Boiler and Pressure Vessel Code, Section IX-Welding and Brazing Qualifications, is normally referenced for original procedure (in-air) and welder qualification for pressure barrier welds, some welding engineers prefer to adhere to its guidelines in their planning of underwater wet welding procedures. Although generally suitable for some stainless steel applications, the current state-of-the-art in wet welding carbon and low-alloy steels is not generally conducive to application of Section IX testing and acceptance criteria. Others have specified AWS D3.6, Type B welds, to meet their requirements for wet welding in carbon and stainless steel applications.

While the test acceptance criteria in some respects is currently somewhat less stringent than Section IX, AWS D3.6 does require more extensive qualification testing and is more restrictive relating to essential variables affected by the underwater environment. Therefore, some utilities are now specifying AWS D3.6, Type O. welding which invokes the test acceptance criteria of another specified code (in the case of stainless steel, ASME Section IX) while accepting the essential variables of AWS D3.6 which consider the underwater welding environment.

3.9.2. Equipment

From an equipment standpoint, there is very little difference in the type of equipment used for surface production welds and underwater welds, although it may be modified in some manner for use underwater. Underwater welding operations require the following pieces of equipment:

- Welding power source
- Underwater metal cutting equipment
- Knife switch
- 90° grinder
- Pneumatic pencil grinder
- Water vacuum system
- Pneumatic chipping gun
- 2/0 extra-flexible welding cables
- Electrode holder
- No.6 or 8 tinted welding glass eyeshield
- Underwater video camera and recorder
- Underwater electrode transport container

The welding power source required to support underwater welding operations must be capable of supplying a minimum of 300 amperes of direct current (d.c.) to the welding electrode holder. In outdoor field locations, use a portable welding machine to provide the power source for welding operations. Within the plant containment area, use an alternating current (a.c.) power inverter to meet the requirements for welding.

In many underwater welding operations, a requirement for underwater metal cutting precedes the welding process. This may be required to remove damaged metal before a repair, or to create better access to the welding site for the diver-welder. In the pool areas, where maintaining water quality is a factor, some type of non-reactive cutting, such as electric arc-water gouging is required. In areas where that is not necessary, use exothermic devices or oxy-arc cutting electrodes. A complete discussion of each of these methods and their equipment requirements are provided in previous sections of this chapter.

Include a knife switch in the secondary circuit to be sure that a positive disconnect is possible when the circuit is not actually in service during welding operations. The switch should be large enough to handle any current that the power source might deliver. Establish a communications procedure between the diver-welder and the person tending the knife switch. The procedure must ensure that the circuit is energized prior to positioning of the electrode a the start of the weld, and de-energized immediately upon "breaking the arc", at completion of the weld.

Use a 90° grinder for all rough metal grinding jobs, and for use in the initial fit-up of the surfaces to be welded. In the primary side pools, the tool most often chosen is a positive-displacement water grinder driven by an electric pump. This tool uses a single supply line which dumps the drive water directly into the surrounding environment. Select water grinders to support pool grinding requirements, as opposed to hydraulic or pneumatic systems, because when driven by demineralized water, they do not present the potential for pool contamination problem of hydraulic grinders, nor do they produce a large volume of bubbles which may obscure the divers' vision like pneumatic tools. In areas outside the pools, such as in the intake water system, hydraulic grinders are preferable to pneumatic grinders, due to their increased power capability and reliability. Do not use a pneumatic grinder in water depths greater than 100 feet, as its effectiveness diminishes rapidly after that depth.

Use an underwater vacuuming system to remove the dross, slag and other waste materials generated underwater during wet welding operations. This will help to clean containment pool areas and return them to their original condition.

Use a pneumatic chipping gun for regular interpass cleaning necessary to clean the slag from weld metal between each welding pass. This device uses a mechanical action to 'chip' pieces of slag which have adhered to the surface of the weld. This is done to provide a suitable surface upon which to begin another weld bead.

Use a pneumatic pencil grinder to remove small irregularities from the weld metal, before beginning each bead pass. The grinder may have several different shaped bits, or burrs, with which various types of fine grinding requirements can be met.

Underwater welding requires a significant amount of manual dexterity. Use extra-flexible welding cable between the surface and the diver-welder to improve dexterity. Use 2/0 size cable to be sure of the least amount of electrical resistance, as this can significantly affect quality and weldability. Terminate the welding cable with an electrode holder, and the grounding cable with a grounding clamp. For this latter purpose, a screw-type C-clamp is an excellent choice.

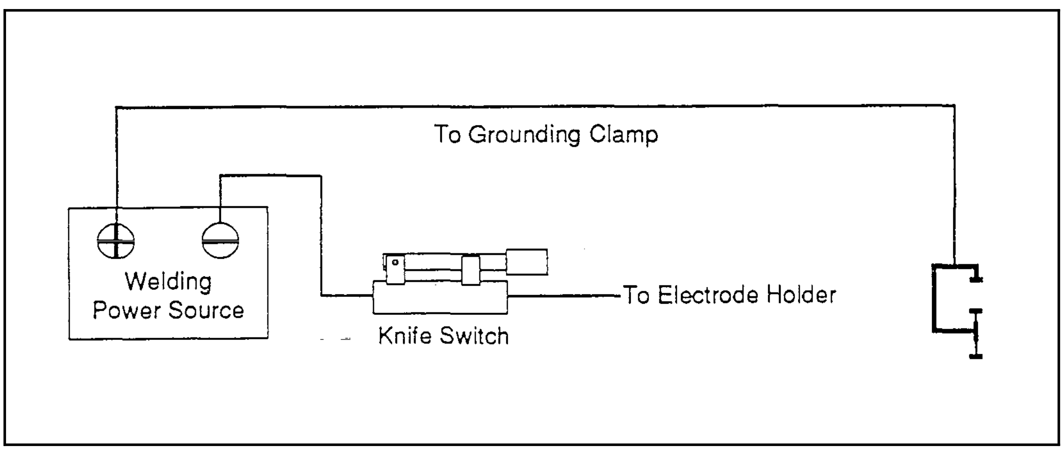
The final piece of equipment required for underwater welding is the welding electrode holder. The holder should be of a type specifically designed for underwater usage. In addition to providing an extra-secure means of clamping the electrode in the holder, these specially designed holders also permit rapid changing of electrodes. They are thoroughly insulated, as required for underwater use.

The tinted glass eyeshield required for underwater welding is normally a No. 6 or 8 tinted welding lens, affixed to the outside of the divers' faceplate. Attach this lens by some means which allows the diver to 'flip-up' the lens when not in use. This will preserve his general visibility.

Use an underwater handheld video camera for final inspection of the welds produced and results achieved. A black and white camera is preferable to color, owing to its greater resolution and light gathering ability. Use a variable intensity light source if auxiliary lighting is required. This will allow for the best balance of light to highlight details in the weld.

3.9.3. Procedure

Inspect all equipment laid out at the dive station. Connect it in such a manner as to provide straight [negative] polarity for the welding electrode. Figure 3-4, in the following diagram, illustrates the proper means of configuring the welding equipment to achieve straight polarity.



WELDING/CUTTING POWER SUPPLY DIAGRAM
Figure 3-4

Once configured, inspect and test the welding equipment to be sure it is safe and operationally ready. To do this, perform the following steps:

- Check each piece of equipment for wear, paying particular attention to the insulation of welding leads, grounding leads, and the electrode holder, all of which will be subject to submergence during operations.
- Inspect each electrical connection in the secondary circuit to be sure that each connection is tight, and that each is securely wrapped with electrical tape, or some other form of insulating material. Current leakage resulting from poorly insulated cables or connections in water will negatively impact welding results far more than in forms of underwater cutting which use electricity, but will also accelerate the break down of the metal in the cables and connections, due to electrolysis.
- Properly ground the power source, if required.
- Check that the polarity setting on the power source is set to provide straight polarity, and that the electrode terminal connection is negative. If the terminal labeling on the power source is illegible, refer to the section on establishing proper polarity discussed in the previous section on underwater oxy-arc cutting.
- Connect the ground lead to a suitable piece of metal. Insert an electrode in the electrode holder. Supply power to the circuit, and position the tip of the electrode in contact with the test metal piece. Using suitable eye protection, have the knife switch closed to complete the circuit. A welding arc should be produced and begin consumption of the welding electrode. Remove the electrode from contact with the metal piece and open the knife switch to complete the system test.
- Position a sacrificial plate at the weld area to minimize the chance of the diver-welder accidentally striking an arc away from the intended weld area. Sacrificial plates can also be useful in protecting adjacent areas during grinding operations.

In proceeding with underwater welding operations, remember to conduct the welding from a stable work platform. If the diver does not have a horizontal surface or vertical member from which to position himself, fabricate a suitable work platform and place it at the work site.

The diver will begin by inspecting the surface to be welded, and cleaning the surface of any paint, marine growth, or other coating. A satisfactory weld cannot be made over coated metal, and even the initiation of the arc may be impossible without prior cleaning. Use a wire brush on a 90° grinder to bring the metal to be welded to a bright finish.

Grind each edge upon which the weld is to be performed, using the 90° grinder and an abrasive wheel, according to the specification for that groove outlined in the welding procedure qualified for that weld.

Evaluate the joint fit-up for the proposed weld, after completion of the cleaning and beveling operations. The positioning and fitting of the metals to be welded is extremely important. It is difficult to compensate for poorly matched or misfit weld grooves. Guide the weld grooves into position and fix for welding. Use spacers to fix the alignment and spacing of the weld gap. Tack stabilizing bar strips across a weld at intervals, to provide the fixed position necessary during welding operations. Use a caliper to establish the weld gap required. In some cases, where good fit-up cannot be completely achieved, the means of correction must be reviewed with and be acceptable to the utility.

Immediately prior to making the production weld, a sample or "confirmation weld" representing the joint configuration, materials, thicknesses, and welding positions involved, should be made underwater in a low-dose area near depth of the actual welding location. This sample is used to verify proper equipment settings, as well as confirm the readiness of the diver-welder. This weld should be accepted by a welding engineer prior to proceeding with the permanent welding. Some utilities impose this requirement on each diver-welder before each dive.

Lay down the root pass after proper fit up is achieved. The root pass, as the name implies, is the first pass of weld metal laid down in the root of the weld, closing the gap. Make this weld, and all later weld passes, according to the welding procedure qualified for the weld. When the root pass is nearly complete, remove the backing bars and proceed with the remainder of the welding

Use the pneumatic chipper to clean slag from the surface of the welds, after completion of each pass, in preparation for the next weld pass. Inspect each pass after it is cleaned, for welding irregularities and imperfections. Use a pencil grinder fitted with an appropriate burr to grind out the flaw, and re-weld before proceeding with the next pass.

Perform each successive weld pass in this manner, until the final pass specified for that weld is completed.

Once completed, have the diver perform a final inspection of the weld using a handheld video camera. Completely inspect each weld along its entire course, and orient the picture in relation to its surroundings. In high-dose areas, it may be desirable to use remote video equipment for inspection of the weld.

3.10. Foreign Object Retrieval

3.10.1. Introduction

From time to time, during visual examinations in the reactor areas and pools, foreign objects of a dimension significantly large enough to warrant recovery will be discovered. Variables which affect the selection of a recovery procedure are the

- physical size and configuration of the object.
- approximate weight of the object, both in water and in air.
- type of of material(s) from which the object is constructed.
- radioactivity level of the object.

If any of these factors are unknown, estimate or measure their values, for planning purposes. These factors, coupled with the relative availability of different recovery methods, will usually dictate the mode of recovery employed as a first choice. These recovery method alternatives include

- ROV manipulation
- Diver manipulation
- Vacuuming
- Magnetic grappling

3.10.2. Equipment

The equipment requirements supporting each of these individual methods are quite different, and except for magnetic grappling, are discussed in depth in their related sections of this guide.

In magnetic grappling, a large, permanent-type salvage magnet is used for such applications. They are capable of lifting several hundred pounds underwater. These magnets have no moving parts, and are fitted with a lifting eye for attachment to the load-bearing line.

A second piece of equipment which has proven to be quite helpful in assisting the diver in inspecting remote areas is a "mechanic's mirror" This simple piece of equipment allows the operator to remotely manipulate the orientation of the mirror, using mechanical push-rods. This device can be useful when attempting to look behind objects located in confined areas.

3.10.3. Guidelines

ROV use for object retrieval invites the use of a remote manipulator outfitted to the ROV, and controlled by the surface ROV operator. With the manipulator, an object can be grasped and held by the ROV, within the design limits of the equipment. A more complete discussion of ROV manipulation is contained in Chapter 2. For the purposes of ROV object retrieval, determine the following information to define the special requirements of ROV work tasks.

Determine the weight of the object in water to assess whether the ROV is sufficiently powerful to lift and travel with the object in tow. ROV payload requirements vary and may be found in the above referenced Chapter, or from the manufacturer. In some instances, where the object is too heavy for the ROV to pick up, additional buoyancy material may be added to the ROV to increase its lifting capacity, within its structural limitations. This will require the ROV to carry a disposable drop weight, or weights, to initially counterbalance the increased buoyancy, until it is possible to attach the ROV to the object to be lifted. After recovery of the object, the ROV can be returned to normal buoyancy, and the jettisoned drop weights can be recovered individually. Another method, is to use an ROV to attach a lift line to a heavy object, which can later be manually hoisted to the surface by topside personnel.

Determine a means of attaching the ROV to the object. The manipulator can function as the primary attachment point, providing that it is not required for any other task during the remainder of the dive, and that it is capable of grasping hold of the object in some fashion. Where this is not possible, use the manipulator to attach the object to the ROV itself, in some fashion, allowing the ROV to act as a payload carrier. A screen or mesh container, attached to the ROV, is useful for placement and containment of smaller objects may be collected by the manipulator during the course of a dive.

The configuration of larger objects will have an impact on the recovery capability of the ROV. Even though the weight of the object in water may be within the payload capability of the individual vehicle, the size and shape of the object will impart a certain drag to the ROV which may make it impossible for the vehicle to maneuver. This is particularly true in secondary system operations, where the ROV propulsion system may have to compensate for water flow or currents in the area in which it is operating. For objects which are particularly long in length, use the ROV to attach a lift line, where the primary lifting can be done from the surface. The ROV can then be used as a trailing guide attached to the end of the object, to provide controlled maneuverability.

Another important consideration in ROV recovery of larger foreign objects, is their weight in air. Solid surface objects which are hollow, or objects made from composite materials, may have a buoyant component to their configuration. As such, when they cross the air/water interface at the surface, their weight may increase substantially. Consider this factor in determining whether the ROV can continue to retain primary possession of the object during the entire recovery operation. It may be necessary to transfer the primary load to an alternate lifting source before surfacing.

In diver manipulation, an object can be quickly and easily retrieved, as long as the object is accessible to the diver directly, or with the help of extension tongs, and, is within the physical capabilities of the diver to lift and maneuver. There are two chief advantages to diver manipulation in the retrieval of a foreign objects:

- the ability to quickly locate the object through a broad range of vision.
- the capability to view the object in three-dimensions.

In the former instance, a diver has a much broader field of vision than does a camera system. Additionally, the diver can adjust his vision far faster, and with greater economy of effort, than an operator-controlled camera system. This allows for the quick location and identification of objects. While it may be true that certain camera systems can provide the viewer with better resolution in low-light conditions, this factor does not outweigh the above advantages, in foreign object retrieval. In secondary system maintenance, where in intake water, the visibility which the camera depends upon may not exist, the divers' sense of touch becomes highly important. The principal drawback to diver manipulation of foreign objects comes in primary side operations where radioactive contamination may be a factor.

Underwater vacuuming, as previously discussed, is best suited to the recovery of numerous small objects. Use it as the primary clean-up method for operations involving metal dross from underwater cutting, or general cleaning operations. Vacuuming can also serve as a valuable secondary method in the retrieval of foreign objects. It provides a means for general area 'sweeping', after a primary method such as remote manipulation has been completed. This provides a certain degree of quality assurance to the operations, where more that a few small objects have been found and retrieved.

In certain situations where a ferrous-metal object, such as a hand tool has been located, grappling with a magnet is an effective means for remote retrieval of the object. Magnetic grappling is also extremely effective when it is necessary to separate ferrous and non-ferrous objects. This could be useful in the salvage of steel parts which may have fallen into the intake canal basin. The size of the magnet selected is based upon the magnetic field strength required for recovery of a given object. Lower the magnet from the surface, or remotely guide it by using a diver or ROV. In intake basin applications, natural bottom conditions, such as a muddy bottom, diminish the magnets ability to attract and hold larger objects.

3.11 Underwater Machining

3.11.1 Introduction

Electric discharge machining (EDM) and metal disintegration machining (MDM) are gaining widespread use where material removal or alteration must be conducted without creating machining chips or other dross whose presence may adversely affect the operation of the component or system. This is especially true in nuclear reactor coolant system components. Residue from either EDM or MDM operations resembles a fine talc-like particulate that can be captured, removed from the cutting area by flushing and subsequent filtration. Since both of these processes require operation in a dielectric fluid, they are easily implemented in an underwater environment.

EDM is a constant voltage process that positions an electrode at a predetermined fixed distance or gap above the work. The distance from the work controls the energy at the cutting surface and can be adjusted as a function of the voltage across the gap. The electrode, normally a graphite compound, and the work must be submerged in a dielectric fluid.

Once the electrode is energized, ion columns are established between the electrode and the work with controlled arcing taking place across the gap that promotes localized heating. Thermal expansion attendant to the locally heated areas causes small molten particles to be lifted off the work surface. Flushing the dielectric in the cutting area causes resolidification of the molten particles and washing of them away from the surface of the workpiece. These particles are then captured and removed by the filtration system. The rate of cutting that takes place is proportional to the amount of energy applied while frequency controls the surface finish of the cut surface.

MDM is similar to EDM but uses a constant current power source and an electrode vibration system to create the cutting pulses. The MDM electrode is brought within close proximity of the work surface and an ion column is formed that allows current to pass through the gap. This portion of the operation causes very high energy to be present in the gap region at the instant just prior to when the electrode makes physical contact with the workpiece.

The constant current power source electronics and control systems are much simpler than with EDM systems, but the resulting control of cut rate, surface finish, and electrode wear are substantially less. MDM is generally faster but less precise than EDM. Reactionary machining forces are also greater than with EDM since the electrode actually touches the work surface so heavier more rigid positioning apparatus must be used.

3.11.2. Equipment

The major components required for EDM and MDM are as follows:

- Power Source and Control System
- Flush & Filter System
- Positioning Equipment
- Electrodes
- Cables and Hoses

EDM and MDM systems for underwater use involve commercially available components that have been modified to include proprietary features for the specific job or application. Review of equipment used in successful past operations indicates that no two jobs were conducted in exactly the same manner or with exactly the same equipment. Each job, even on similar or identical tasks, has progressively demonstrated better results that are in part do to experience and continuous upgrading and modification of equipment components.

Power Source and Control System. EDM power sources involve precision low-power constant voltage power supplies with sophisticated electronic control while MDM requires high power constant current power with control similar to a normal shielded metal arc welding power source. Power sources are sized for each specific application. For jobs where the size of the cut is large, it is common to parallel power sources to gain additional power.

Flush & Filter Systems. The ability to continuously flush freshly cut material away from the cutting cavity is of extreme importance. Pumping and flushing configurations are designed based on the application, electrode configuration, and amount of clearance that will be present between the electrode and the workpiece. Most flushing systems include a means for capturing the exiting fluid and suspended cut particles and remove them from the area by means of elaborate filtering systems. Filter system design and its required effectiveness is also a function of the specific job.

Positioning Equipment. The equipment for positioning and implementing either EDM or MDM will reflect the accessibility, accuracy, size, and surface finish of the specific task. Stationary as well as robotic manipulated end effecters have been used successfully. EDM positioning equipment does not require the rigidity needed to overcome reactionary mechanical forces associated with MDM since its electrode never actually touches the workpiece, but both methods have been remotely deployed in many successful operations.

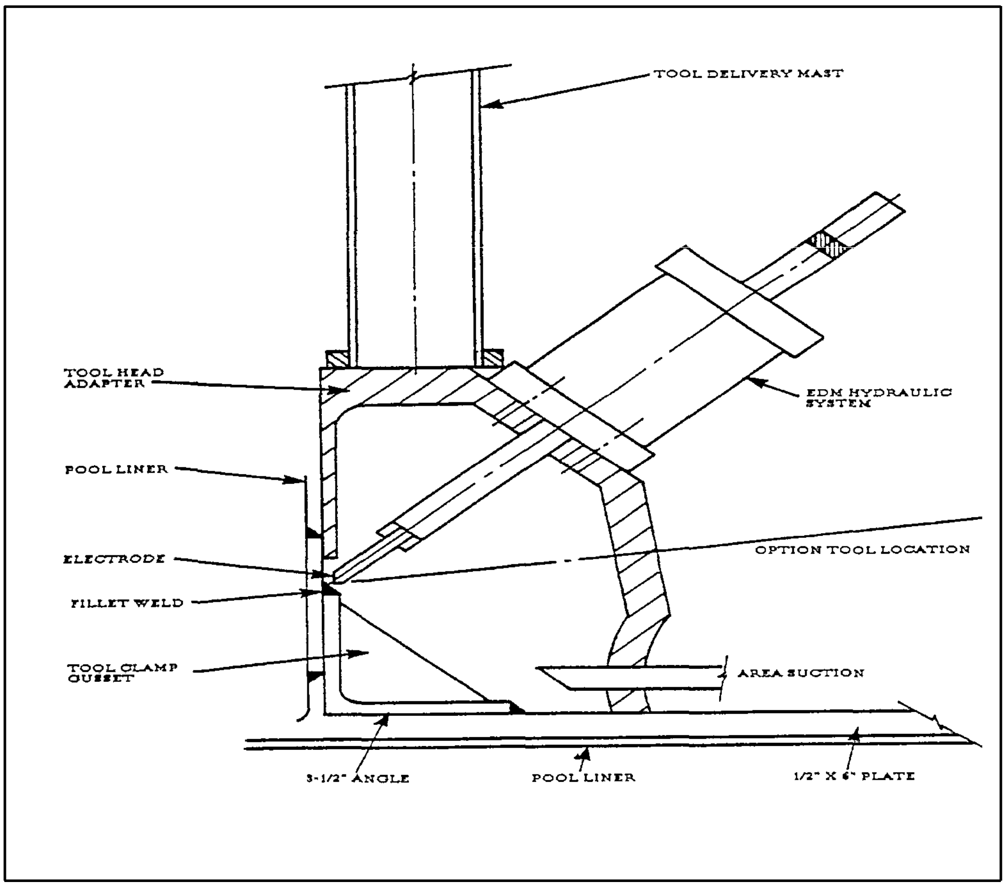
Electrodes. Electrodes for both EDM and MDM are typically made of graphite or similar material compositions. The ease of machining or fabricating the electrode material enables virtually any shape to be addressed by simulating the geometry of the hole or penetration to be cut. Electrodes involving numerous different shapes and sizes have been used to remove shapes including cylinders, plugs, squares, equilateral triangles and even hemispherical shapes.

Cables and Hoses. Cables and hoses for delivery of cutting electrical current, supply and withdrawal of flushing water, and control wiring for positioning equipment will be job and application specific. Cable and hose lengths should be maintained as short as possible to minimize losses, but lengths up to 100 ft have not been a problem.

3.11.3 Procedures

Set-up of EDM and MDM systems are typically straightforward. The power source, interconnection cables and hoses, electrodes and holders, positioning and manipulation equipment, and control panels are usually assembled as near to the cut location as possible.

Actual techniques used in EDM and MDM utility applications are currently held as proprietary by the firms performing the work. Each application generally requires unique approaches, evaluation and development of operational parameters. An example of EDM application is shown below.



UNDERWATER EDM SYSTEM AND ANGLE SUPPORT
(Courtesy of Brand Utility Services)
Figure 3-5

3.12 Corrosion And Protective Coating Inspection

3.12.1 Introduction

Underwater protective coatings serve two important functions in normal use. Primarily, they serve to extend the service life of essential plant components by preventing corrosion. As a secondary function, when applied in radiological areas, they also usually serve as an improved decontaminable surface. In safety related (coating service Level 1) immersion areas, epoxies and inorganic zincs are generally specified for service. These coatings provide good performance and are capable of meeting radiation tolerance, design basis accident (DBA), and other specified testing required by ANSI N101.2, "Protective Coatings (Paints) for Light Water Nuclear Reactor Containment Facilities". This standard has been superseded by ASTM D3843-80, "Standards Practice for Quality Assurance for Protective Coatings Applied to Nuclear Facilities". Coal tar or coal tar epoxies may be used in place of standard epoxies and inorganic zincs for non safety-related structures, such as intake and discharge gate structures, immersed piping systems, and storage tanks.

Standard epoxies, coal tar, and coal tar epoxies protect by providing a semi-impermeable barrier to the substrate. Inorganic zinc coatings are anodic to the substrate and protect by corroding preferentially to carbon steel. When properly applied and maintained, both types of coating systems will perform well for many years. Proper maintenance includes periodic inspection and touch-up of coating deficiencies.

Many immersion areas at a nuclear facility are not routinely drained for inspection due to radiological, operational, and/or economical constraints. In addition, immersion areas coated with copolymeric systems (epoxy) may become brittle when subjected to wet/dry cycling, or intact blisters may fracture, exposing the substrate.

Inspections which solely requires qualitative visual inspection can often be performed more cost-effectively by remotely operated vehicle (ROV). However, the effectiveness of a simple inspection ROV which does not possess an auxiliary cleaning tool system may be limited in areas where sludge accumulation impairs visibility of the inspection surface. Corrosion and protective coating inspections for the nuclear industry, and particularly in safety-related systems, require that quantitative measurements be taken in addition to qualitative visual observations.

The currently preferred method of performing these types of inspections is through the use of qualified divers who are experienced in performing, documenting, and evaluating protective coating and corrosion inspections. Inspection personnel must be trained and certified in accordance with applicable industry standards, provided in ANSI N45.2.6, "Qualifications of Inspection, Examination, and Testing Personnel for the Construction Phase of Nuclear Power Plants" Level II or Level III inspectors are recommended for all structures which are safety-related.

Develop written procedures which provide for qualitative and quantitative inspection methods, documentation, and data analysis. Identify and evaluate coating and substrate deficiencies in accordance with applicable industry standards. These standards are generally provided by Steel Structures Painting Council (SSPC), National Associated of Corrosion Engineers (NACE) and the American Society For Testing Materials (ASTM).

Coating deficiencies generally fall into two categories. The first are those which have the potential to generate loose debris such as inter coat or substrate disbanding, and blistering of the coating. These deficiencies are generally of concern in safety-related areas because loose debris may restrict f low through emergency core cooling systems (ECCS) which are essential to plant operation and safe shutdown. Second, are those which result in cross-sectional loss of the substrate due to general or localized corrosion.

Typical immersed structures and storage vessels which require corrosion and protective coating inspection, in boiling-water reactor (BWR) and pressurized-water reactor (PWR) facilities, are shown in the following Figure 3 6.

TYPICAL UNDERWATER CORROSION INSPECTION AREAS
Figure 3-6

BWR	PWR
Condensate Storage Tanks	Cask Decon Collection Tanks
Demineralized Water Tanks	Caustic Batch Tank
Fire water storage tanks	Condensate Storage Tanks
Floor Drain Holding Tanks	Intake and Discharge Structures
Hot Wells	Fire water storage tanks
Intake and Discharge Structures	Potable water tanks
Potable water tanks	Rad Waste Storage Tanks
Rad Waste Storage Tanks	Reactor Water Holding Tank
Refuel Floor Cavities	Refuel Floor Cavities
Steam Dryer/Separator Pit	Upper Head Injection Tanks
Suppression Chambers	Waste Condensate Tanks
Test Tanks	

NOTE

Some of the above areas in various facilities may not have top penetrations designed to accommodate diver access. Evaluate whether tank contents can be lowered sufficiently to allow utilization of a side access way, if available. Otherwise, determine cost-benefit of installing an access way in the tank.

3.12.2 Equipment

Refer to section 1.3, "Diving Equipment", for information on diving equipment and procedures necessary for the specific type of underwater operations (contaminated vs. non-contaminated) planned.

In addition to required diving equipment, the following Figure 3 -7 provides a general list of inspection equipment and instruments and a brief description of their use for underwater corrosion and protective coating inspection:

TYPICAL CORROSION INSPECTION TOOLS
Figure 3-7

Tool System	Description or Use
Soft bristle brush	Hand cleaning of coated surfaces
Hand wire brush or scraper	Hand cleaning of light corrosion
Pneumatic grinder	Power cleaning of heavy corrosion
Suction cups, W/handles	Maintain diver position on vertical structures
High intensity light	Improve inspection visibility
Dry film thickness gage	Measure coating thickness
Depth micrometer	Measure metal loss due to corrosion
Steel rule or tape measure	Perform location or size measurements
Underwater 35mm camera	Photographic documentation
Underwater video camera	Video documentation
Inspection forms	Document inspection results

For the most part, the tool specifications for the above tools required for the performance of corrosion inspection, and their usage, do not require explanation, with the following two exceptions:

Calibrate the dry film thickness gauge used to the Certified Coating Thickness Standard maintained by the National Institute of Standards and Testing (NIST), formerly National Bureau of Standards (NBS). The gauge must be certified by this Standard to be accurate to within +5% of true.

The depth micrometer used for measuring depth of corrosion should be accurate to within ±.5-mil. Calibrate against a standard which is within ±.1-mil of true.

3.12.3 Procedure

Begin by reviewing all specification requirements, applicable drawings, inspection procedures, and system tag out procedures with the contractor to assure his understanding of all technical, quality, and safety requirements associated with the project.

> **CAUTION**
>
> **As part of this review process, ensure that all pumps, valves, and inlet/discharge piping associated with the system to be inspected are properly deactivated, and tagged and/or locked in the safe position, prior to conducting diving operations.**

Establish and maintain an equipment control inventory to ensure that all equipment used during the inspection operations is removed from the inspected system prior to completion of operations.

Ensure that the contractor performs the corrosion and protective coating inspections in accordance with written procedures which comply with the project specification. One method to accomplish this is to segment the inspection operations in a manner which allows close monitoring of contractor preparations to begin operations, and periodic oversight, such as at the midpoint or conclusion of each segment Include in these procedures, the following items:

- Applicable reference codes, standards and other compliance documents
- Work scope and purpose
- Inspection methods and required instruments
- Acceptance criteria
- Documentation requirements

Select the appropriate reference codes and standards for the inspected system and the type of inspection being performed. Write the work scope and purpose of the inspection in a clear, concise, and logical manner. Confirm through discussion that the contractor demonstrates his clear understanding of these items, prior to commencing operations. Identify in the inspection method the type of inspection to be performed for each coating system, and establish as precisely as possible, the manner in which each will be inspected. Also list the tools, instruments, and consumables required for each inspection. Develop acceptance criteria which clearly delineate the various levels of acceptability, to the extent possible, and particularly in the area of pass/failure acceptability.

> **NOTE**
>
> **In scheduling inspection operations, allow sufficient lead time for development of certain inspection acceptability standards, such as the maximum allowable loss of cross sectional metal in a storage vessel or pressure vessel, which may require a substantial amount of preliminary engineering and data research to establish.**

Include in the documentation requirements, the type of format(s) required (e.g., inspection forms, video, still photographs, etc.), the specific criteria to be documented by each, and the level of detail required.

The key to successful coatings inspection is to perform all protective coatings and corrosion inspections in a systematic manner. Divide large structures into logical smaller units which are identifiable and easy to document. Begin by performing a general qualitative visual inspection to identify the general condition of the structure and protective coating. Specify the total surface area to be inspected and identify the area in the written procedure. Consider that it may be important to inspect a greater percentage of the total surface area in essential storage tanks and pressure vessels, such as suppression chambers in BWR facilities, than in other non-essential systems.

Identify and rate coating and substrate deficiencies in accordance with those recognized industry standards listed in section 3.11.1 Ensure that the results are documented in the appropriate manner, as the inspection is performed, rather than waiting to record the data upon completion of some interim milestone. This will minimize the risk of incorrectly recording or omitting inspection data. Check that all measuring and testing equipment planned for use has been properly calibrated prior to operation.

Instruct the contractor to report material deficiencies which are of concern as soon as possible, in accordance with the pass/failure criteria specified in pre-job planning.

The following list names general coating defects and substrate corrosion conditions to be identified:

- blistering
- cracking
- disbonding
- discontinuity
- uniform corrosion
- localized corrosion
- pitting corrosion
- corrosion nodules
- tiger striping
- spall
- score
- surface mark

Blistering is characterized as the formation of bubbles in a cured, or nearly cured, coating (paint) film.

Cracking is characterized as the splitting or disintegration of coating (paint) by breaks through the film to the substrate.

Disbonding is characterized as the destruction of adhesion between a coating and the coated surface to which it is applied.

Discontinuity is characterized as any interruption in the normal physical structure or configuration of a part, such as cracks, taps, seams, inclusions or porosity. A discontinuity may or may not affect the usefulness of a part.

Uniform corrosion is characterized as the corrosion over a surface which maintains both a uniform appearance and rate of corrosion.

Localized corrosion is characterized as a galvanic cell resulting from inhomogencities between areas on a metal surface in an electrolyte. The inhomogencities may be of physical or chemical nature in either the metal or its environment.

Pitting corrosion is characterized as localized corrosion which has taken the form of cavities at the surface of the metal.

Corrosion nodules are characterized as corrosion deposits which typically accumulate at localized corrosion cells. These nodules are also often referred to as tubercles.

Tiger striping is associated with inorganic zinc coatings only, and is characterized as alternating light and dark markings.

A span is characterized as an area of missing coating.

A score is characterized as a groove whose width is equal or greater than .005-in.

A surface mark is characterized as a groove whose width is less than .005-in.

3.13 High Accuracy Ranging and Positioning

3.13.1 Introduction

The ability to accurately range and locate the position of an underwater object can be of significant value in performing and documenting many types of inspection operations, from ultrasonic testing to service water intake inspection. Presently, there exists a single system, known as SHARPS, which is capable of acoustically locating a coordinate position in all three dimensions with a significant degree of accuracy. While NMAC does not endorse either the SHARPS system or its manufacturer, we believe that the potential maintenance-related applications of the technology are sufficient to warrant presentation of the system as part of this guide.

SHARPS is an acronym for Sonic High Accuracy Ranging and Positioning System. This proprietary system, owned by Marquest Group, Inc., Bourne, MA, was designed for precise underwater survey, tracking, and navigation applications. It is well suited for adaptation to diver, underwater remotely-operated vehicle (ROV), and other types of telerobotic intervention. In principal, the system uses a number of underwater acoustic transceivers to create an "acoustic net", within which the position of a "target transceiver", held by a diver or attached to an ROV, can be accurately determined. This is accomplished by measuring the length of time required, for each of the transceivers making up the net, to receive each acoustic pulse from the target transceiver. These values, along with known values relating to the positioning of the net transceivers, are processed by a proprietary computer program to produce an extremely precise indication of the target transceivers' relative position to the acoustic net.

SHARPS uses a short, high frequency 300 KHz acoustic pulse to achieve precise positioning. Accuracy ranges from less than 1-cm. in very localized areas, to 2-cm. at maximum range. Maximum range for this system is approximately 100 meters in salt water, and up to 180 meters in demineralized or fresh water. Because of the manner in which SHARPS transceivers acquire and process the acoustic signal from the target transceiver, the system is vulnerable to signal interference in the pass band between 240-360 KHz. If there is concern about possible signal interference from existing or transient sounds in the operating environment, use a frequency spectrum analyzer to evaluate the potential for signal,interference at each work location. Adjustments to the position of the target transceiver away from the source of noise, and to the transceivers comprising the acoustic net, can compensate for such interference to some degree.

The system has demonstrated performance in utility maintenance applications for production of precise bathometric mapping of the natural bottom areas, and as an accurate position referencing system for ultrasonic testing of a torus. In the former application, SHARPS-equipped ROV's have accurately mapped sedimentation, debris accumulation, and precise bottom profiles at the foot of hydroelectric dams, and in areas surrounding the ocean service water intake structure at a nuclear power generating station. Both applications required that the output from the SHARPS system be integrated with the output from the ROV's onboard side-scan sonar, to produce the bathometric map. In the torus inspection, another SHARPS-equipped ROV was fitted with an ultrasonic testing probe, and a random non-destructive evaluation of the corrosion condition was performed over 50 percent of the torus interior.

Due to the use of a high frequency, short-duration acoustic pulse, and when used with hard-wired acoustic transceivers to make up the net, SHARPS is virtually immune to multipath interference problems common to many underwater acoustic positioning systems. This factor makes the system ideal for use inside tankage and other closed spaces, where precise positioning of equipment is required. For open-water applications, SHARPS transponders are available in a configuration which does not require cabling.

With a data acquisition rate of up to 10 samples per second, SHARPS can also be used as the basis for an ROV control system. It can provide sufficient position, velocity, and heading information to control the operation of an ROV in real time. The implication of this fact is that a SHARPS-equipped ROV, whose propulsion system has been integrated with the positioning control system, can effectively be programmed to follow a set course, as during an inspection, stopping at Redefined waypoints to perform data acquisition functions, such as video inspection or ultrasonic testing. Further, as an alternative method of programming, the ROV can be manually guided by the operator over a set course, recording course and waypoint data along the route. Henceforth, the ROV can repeat the same course and waypoint route without the need for experienced operator intervention or control, thus effectively making the unit an autonomously-operated vehicle (AUV).

The value of such an AUV to the user lies in its ability to perform automated operations, identically repeatable on a period-over-period basis. This function makes it especially appropriate for the performance of repetitive inspections to assess relative change to materials or systems over time.

In theory, trained operators could perform the initial inspection, developing course and waypoint information for ROV control and data acquisition. Subsequently, the ROV would perform all future inspections by traversing the same course and acquiring the same type of data at the same way points, automatically. Such data could then be easily exported to a spreadsheet or graphics plotter for evaluation and period-over-period comparison.

3.13.2 Equipment

SHARPS equipment can be utilized easily by both divers and ROV's. The equipment package is compact, and easily portable. For ROV utilization, Marquest has previously evaluated and configured SHARPS to accommodate a number of ROV types common to utility operations, including:

- Benthos *MiniRover II*
- Benthos *SeaRover*
- Deep Ocean Engineering *Phantom 300*
- Deep Ocean Engineering *Phantom HVS4*
- Deep Ocean Engineering *Phantom S2*
- HydroVision *Hyball*
- RSI *SeaMoor*

The SHARPS system consists of the following components:

- acoustic "net" transceivers
- cabling
- acoustic "target" transceiver
- 386-25 MHz computer and proprietary software
- uninterruptable power supply (UPS)

The acoustic net is usually made up of three(3) transceivers, that being the minimum number required to establish position and ranging in all three planes. Additional transceivers can be added as desired, to increase the accuracy or area of coverage provided by the net. A practical upper limit for most net configurations is ten (10) transceivers. The transceivers, themselves, are stainless steel and weigh approximately 1.0-kg. in air. Their dimension is approximately 1. 75-in. in diameter by 8-in. in length. They require 28 vDC @ 25 mA from the SHARPS 110-120 vAC power supply.

The net transceivers are connected to the computer by means of RG-58 coaxial cable, covered by a nylon abrasive jacket containing a kevlar strain-relief component.

Standard cable length is 150 meters, with optional lengths available to 300 meters. All cables are depth rated to 500 meters. Wireless transponders may not provide the same degree of multipath interference immunity in tanks and vessels as their hardwired counterparts.

The target transceiver is identical in configuration to the net transceivers, except that it transmits an acoustic pulse when actuated. The pulse can be triggered either manually by a diver, or electronically by an ROV or other telerobotic device. In the case of an ROV, the target transceiver can be operated either as a wireless transponder, or as a cabled pinger, and can be powered by a twisted, shielded pair [wire] contained within the ROV's tether. Target transceivers to be diver-actuated can be pistol-grip mounted to facilitate ease of use.

The computer system supplied to support SHARPS data acquisition and processing is at least a 386-25 MHz model. Applications requiring coprocessing of an ROV control system or high data acquisition rates may require upgrade to a 386-33 MHz or 486-25 MHz model computer in order to adequately manage all central processing unit functions in real time.

The proprietary software developed for SHARPS provides a high resolution, real-time color tracking data display, with an optional 3-D navigation background display. The software provides the user with real-time data display, change of axis, zooming, and communications port interface. It consists of a range of menu-driven set-up routines which include:

- speed of sound calculations for the appropriate media
- auto-calibration of the acoustic net
- data acquisition parameters and options
- graphics editing functions

Acquired data is written to disk [stored] in ASCII file format, to facilitate ease of export to spreadsheet, statistical, and computer-aided drafting (CAD) programs for further manipulation. The software also provides an on-line HELP' function to assist the operator in system set-up and operation.

The uninterruptable power supply (UPS) serves two functions. It provides a standby source of power in the event of a power failure, and also provides a stable source of power to the computer necessary to eliminate potentially harmful current fluctuations which might result in equipment damage or data loss. A UPS of any output wattage is highly desirable. All UPS's will stabilize power fluctuations and protect equipment and data, and higher wattage units will provide longer standby time in the event of a power loss.

3.13.3 Procedure

In evaluating a prospective maintenance task, there are two main reasons for selecting SHARPS as a support system. The task must either require precise knowledge of a position coordinate, or, it must be an inspection or maintenance task which will be repeated on a periodic basis. This latter type of task is best suited to ROV intervention, due to the capability of SHARPS to provide autonomous control of the vehicle propulsion system for exact relocation and repeatability.

If the maintenance task to be performed is an ROV-supported task, the first step in assessing SHARPS suitability for task performance is to determine the type of ROV to be used, and whether SHARPS currently supports that model. This information is available from the contractor. If SHARPS has already been configured and tested for that ROV type, then integration and testing of the system to the ROV can be accomplished within one (1) day onsite. If, however, SHARPS has not yet been configured for a given vehicle type, it will require approximately 3-4 days onsite for the contractor to evaluate the ROV system, integrate SHARPS hardware to the ROV, and reprogram the SHARPS software to match that ROV type. In either case, perform a final test of the SHARPS/ROV system, in a body of water of sufficient size to allow the configuration of a minimal acoustic net, to assure successful ROV integration and final calibration of the SHARPS system.

When planning to use SHARPS, and after identifying the delivery system [diver or ROV], contact the contractor to determine what additional interfacing might be required to support other equipment used in data acquisition, such as sides-scan sonars or ultrasonic test probes. Evaluate the proposed work site to determine the level of noise present from pumps, motors, or other equipment planned for use during the SHARPS operations. Discuss with the contractor whether a frequency analyzer, coupled to a hydrophone, should be used to evaluate each work site for potential signal interference.

Upon mobilization of equipment, plan to provide the contractor with one (1) day of onsite time for post-shipping inspection of equipment, and performance of necessary system checks and calibrations. Remember that the contractor will require a body of water in which to test the SHARPS system. If an ROV is used, it will also require a pre-operations check-out dive, and depending upon its size, a separate method or

If the equipment will be used in a radiologically-contaminated area (RCA), inform plant health physics personnel of the need to perform a baseline radiological assessment of the equipment prior to transferring the equipment to the RCA for service.

When establishing the acoustic net, the greater the differential distances, in all three planes, of the first three transceivers from one another, the greater the degree of position accuracy for the SHARPS array. Additional transceivers can be added to the net to:

- increase the area covered by the acoustic net.
- increase the position reliability in larger area nets.
- compensate for acoustic 'shadowing' caused by underwater obstructions to direct line-of-sight pathways between the acoustic signals.

If it is desirable to be able to correlate period-over-period results from the SHARPS survey, an important planning consideration becomes the choice of locations for the acoustic net transceivers. Locate chosen positions for at least two of the transceivers at known, fixed reference points which can be repeatedly accessed at each inspection period. Endeavor to position transceivers so that they are both approximately equidistant from each other, and surround the work area perimeter. Choose wide open locations which offer the least degree of acoustic shielding from obstructions in the area. In other words, do not position a transceiver directly behind an obstruction, in relation to the remainder of the array.

In order to survey an area larger than the practical size of the acoustic net, either add additional transceivers to increase the size of the array in a manner recommended by the contractor, or plan to segment the operations to allow for repositioning of the array transceivers at various intervals. Repositioning can be accomplished either manually, or through telerobotic manipulation. In each repositioning, leave two (2) transponders in their previous positions, to act as reference points for calibrating the new net position. After each repositioning, use the target transceiver to initiate a recalibration of the array transceivers.

After the net has been established and all equipment tested, operations consist of tracking the target transceiver as it moves within the net. Upon initial entry into the acoustic net, the target transponder is positioned at two (2) known coordinates, determined by the contractor. The contractor will perform a short duration series of calibration procedures to establish the origin and orientation of the coordinate reference system for the net array, to which all further position information will be tied. Prior to initiating operations, verify that the contractor has measured in situ conditions which might effect the speed of sound transmission through the water, such as water temperature, thermoclines, or salinity, and that the SHARPS equipment is calibrated accordingly. Ensure that these measurements are repeated at any time during operations when it is reasonable to assume that the physical in situ conditions have changed. After completing establishment of the net, and calibration of the equipment, proceed with the data acquisition phase.

Ateach data point that is, a reference coordinate where each data acquisition occurs, the diver or ROV operator will position the acoustic transducer head and initiate an acoustic pulse from the target transceiver. The transducer head is a small piezoelectric ceramic hemisphere located at one end of the transceiver. As the computer receives the pulse from each of the net transceivers, it will interpolate the position of the target transceiver within the net and record that data point to disk. Data acquisition proceeds in this manner until all data points are recorded.

Perform the recalibration procedures after every repositioning of the net array, or after a break in operations.

Chapter 4

Underwater Maintenance Tasks

4. UNDERWATER MAINTENANCE TASKS

This Chapter deals with a presentation of some of the underwater maintenance tasks which have been performed in nuclear power plants to date. It is intended to give an historical perspective to maintenance requirements, as well as provide an overview of each task, equipment required for its completion, and general guidelines covering its performance. The tasks included, as well as the level of information presented, is based upon the results of surveys of both nuclear utility maintenance staff and underwater services contractors.

The condition of the work environment and the extent of preparation directly affects the outcome of the repair. Water temperature, work platform configuration, contamination levels and water depth, etc., all affect the working time a diver can spend underwater and the potential radiation exposure a diver may receive. An overview of the preparation involved in underwater repair operations, such as equipment, mock-up training, welding qualifications, decontamination, and radiation barriers will be further discussed in this section.

4.1. Gate Valve Maintenance

4.1.1. Introduction

In the past, several plants have discovered that the nuts and bolts originally used to secure the gate valve to the fuel transfer canal flange have shown signs of corrosion. Following standard preventive maintenance policies, replace both the nuts and bolts at the first opportunity.

These transfer canals and valves are about 36" in diameter. Flanges of this size normally require about thirty-six (36) nut and bolt sets, with each bolt measuring about 1 1/8"-1 1/4" in diameter. To prevent repeat maintenance requirements, select compatible stainless steel nut and bolt sets as replacements.

In situations where the internal components of the valve may require some type of maintenance, such as in replacement of the seals, remove the entire valve assembly. Bring it to the surface for refurbishment. This lessens the chance of damaging the pool liner, which escalates whenever underwater activities such as this take place. This also allows for a complete inspection of the valve components, as well as testing of the valve before reinstallation.

4.1.2. Equipment

The replacement of nut and bolt sets is fairly routine, in underwater maintenance activities, and as such, requires only a few special tools in addition to the normal diving equipment. These include a

- Pneumatic impact wrench
- Standard and Deep-well sockets
- Box-end wrench
- 10 lb. heavy maul
- Air compressor and 3/4" pneumatic CP hose

- 45° swivel joint
- Torque wrench
- Replacement nut/bolt sets
- Tool basket

A pneumatic impact wrench is used to remove and reinstall the nuts and bolts. While this can be done manually, using a pair of box-end wrenches, it is much easier and less time consuming to use the air impact wrench. These tools come in size ranges from 1/2"-1 1/2" square drives. A 3/4"-1" drive is most suitable for this type of task. Pneumatic wrenches of this size require a minimum of 40-60 cfm, at a delivery pressure of 90 psi over bottom pressure, to work efficiently. Check the tool to be sure that no incompatible lubricants have been used in maintaining the tool. Do this before allowing its use in the reactor pools.

To be sure that the sockets selected are the right size for the fasteners, have both standard and deep-well sockets on hand, sized to fit both the nuts as well as the bolt heads. Depending upon the original installation, it may be necessary to alternately work on the nuts or the bolts, depending upon their individual location on the flange.

Use a box-end wrench as a back-up to the impact wrench, during loosening and tightening of bolts. Box-end wrenches are less likely to fall of the bolt head while the diver is using the impact wrench on the nut. If possible, the wrench should have both an open and a box end, as the open end is more easily used by the diver when only a hand wrench is required. Consider the length of the wrench handle with regard to possible physical limitations in usage at the valve site.

When removing the bolt sets from the flange, a heavy maul may be required to provide the necessary force to free 'frozen' nuts from bolts, before using the impact for removal of the nut. The maul should have a short handle and a broad striking face, to improve its ease of use and effectiveness underwater. Mauls weighing more than 10 pounds become increasingly difficult to use effectively underwater, as are mauls with handles longer than 18 inches.

In addition to the sockets, the impact wrench will require a separate LPHV (Low Pressure High Volume) air compressor and air delivery hose from the diver. There are a number of reasons for this, however, the primary reason is because pneumatic tools require such a large volume of air that they would take the air supply away from the diver each time the diver used the tool, if they were supplied from the same compressor and volume tank. While the compressor need not normally produce more than 160 psi, it must be capable of producing a minimum of 60 cfm. This is the volume of air required to drive the impact wrench. Use a 3/4"-1" CP-type hose to supply air to the impact wrench. These connections each contain an O-ring type gasket necessary for a proper seal. Each connection should be wired closed.

The sockets may also require a 45° swivel joint, for installation between the socket and the impact drive shaft, to help its installation upon a nut or bolt, in spite of individual axial restrictions.

Use a manual torque wrench for final installation of the bolts at equal loading to the flange face. Once again, local access restrictions will be a consideration in the length of the torque wrench selected. If necessary, use a shorter torque wrench, with a torque multiplier, to achieve the necessary torque loads on each bolt.

Size replacement bolts sets the same as those existing bolts being removed from the flange. This will simplify operations and reduce the time required to completion, by eliminating the need to change socket drives as bolt sets are removed and changed.

Use of a tool basket is good operating practice, to keep loose parts together, as well as providing a container in which to store tools when not in use. Use it to reduce the chance of damage to the pool liner by containing the tools and bolt sets as they are removed.

If valve removal or replacement is to take place, the diver will also require the ability to attach the valve body to the overhead crane, or other lifting device, for recovery to the surface. This additional work, plus the reinstallation of the valve, will require the following additional pieces of equipment:

- Lifting bridle assembly
- Stainless steel drift pins (2)

Make the lifting bridle assembly of 1-4 slings of equal length, deployed from a central lifting ring, attached to a lifting block. Each sling ends in an eye, to which a lifting point on an object can be shackled

Use two stainless steel drift pins to align the bolt holes between the two flanges, during reinstallation. Each of these tapered drift pins should be between 18"-24" in length, with 50% of their length sized just under the diameter of the bolts used. Taper the balance of the pin to a point.

4.1.3. Procedure

Vacuum the pool area around the valve to decontaminate the area in preparation for the work to begin.

Properly configure all equipment at the dive station. Start the LPHV air compressor used to supply the impact wrench and test the air delivery to be sure of both adequate pressure and volume. Do this by cycling the compressor, by draining air from the volume tank until the compressor starts and watching it until the compressor shuts off at the desired delivery pressure.

After connecting the CP hose and impact wrench to the compressor, place the impact on a fixed nut on the surface. Run the impact to be sure that it is 'hitting' solidly, and will work well underwater when required. Insert a retaining pin in the keyway of the socket and drive shaft to prevent the accidental spin-off of the socket during operations. Tape the keyway containing the pin securely, so that the pin does not work its way out during use.

Inspect the maul, box-end wrench, impact wrench, torque wrench, and bolt sets as they are placed in the tool basket. Hand thread each nut and bolt set to be sure that all nuts can be easily threaded upon the bolts. Check that none of the bolt threads are damaged to the extent that the diver would be unable to use them underwater. Tie the impact wrench off securely to the interior of the tool basket to be sure that it does not become dislodged while the basket is being lowered to the work site. Set the torque wrench to the desired load and manually lock it in position. Confirm the torque with the diving supervisor, before placing it in the tool basket.

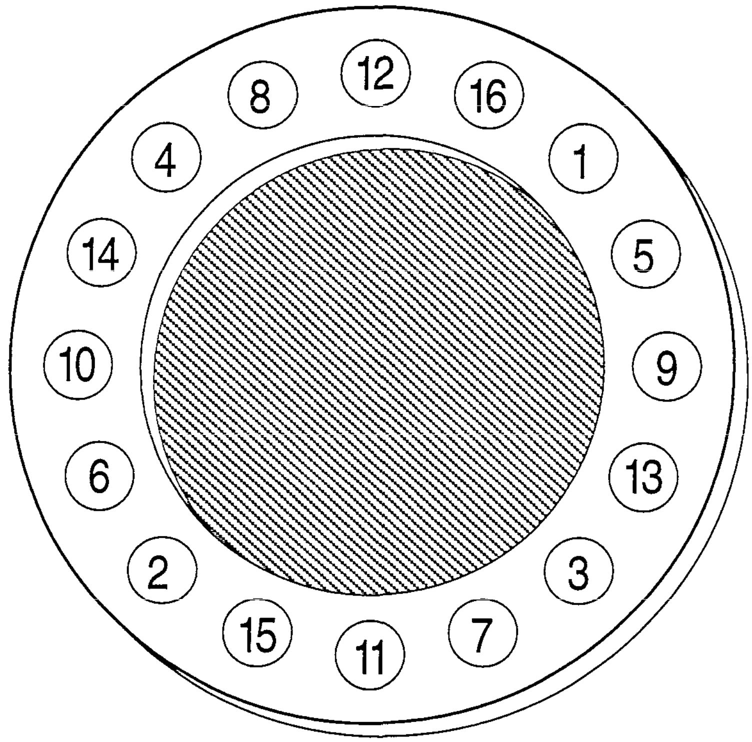
Hook the tool basket to the overhead crane and lower it to the work site area, with final positioning on the bottom of the pool done by the diver. Have the diver inspect the flange and orient himself to the work.

Begin replacement of the bolt sets by instructing the diver to remove a specific bolt, such as the 12:00 o'clock bolt. Identify successive bolts by their orientation to that bolt. Do this by counting a number of bolt holes from a reference point on the flange, such as the 12:00 o'clock bolt hole position, either clockwise or counter-clockwise, to arrive at a specific bolt.

Use the impact wrench and appropriate socket to loosen the existing bolt and reinstall the new stainless steel nut and bolt set. If there has been a significant amount of corrosion, it may be necessary to place the box-end wrench on the nut, and strike it with the maul in order to succeed in breaking the initial 'set' of the nut and bolt in the flange.

After removing the existing bolt and nut and placing them to one side of the tool basket, select a new nut and bolt set from the basket and install in its place. After being hand threaded and run up just tight with the impact wrench, use the torque wrench, with a multiplier if necessary, to tighten the bolt to the specified tension.

After the first replacement is completed, check off that position on a diagram of the flange. The diagram should show the bolting pattern. Install the rest of the bolts in a similar manner, according to the pre-determined bolting sequence. In the absence of any specific pattern required, use the following typical bolting sequence for all flanges:



TYPICAL FLANGE BOLTING SEQUENCE
Figure 4-1

Install the four primary bolts first. The primary bolts are those four bolts which are installed at 90° from each other on the flange, and evenly distribute the load around the perimeter of the flange. They are best located at the 2,4,8, and 10:00 o'clock positions. This positioning ensures that the area which is normally most difficult for the diver to reach, the bottom of the flange, is not also the location of one of the primary bolts. If local obstructions exist which might inhibit the divers' ability to tighten a bolt effectively, shift the recommended sequence to be sure that the primary bolts are all freely accessible.

If the valve is to be removed to the surface for refurbishment, begin by attaching the lifting bridle assembly to the valve body at its lifting points. If the object to be lifted does not have any lifting padeyes, wrap the slings around the object in such as manner as to support the object. Then shackle the eyes of the slings back into the standing length of the sling itself. As the object is lifted in this fashion, the sling tightens around the object, "choking" the load.

Complete the attachment of the sling by taking a slight upward strain on the valve with the crane. This serves two purposes, 1) to take out any slack or 'stretch' in the slings, and 2) to support the weight of the valve body, thereby taking any strain off of the remaining bolts. This allows for the easy removal of remaining bolts from the flange.

Remove bolts from the bottom and sides of the flange, first, leaving the bolt at 12:00 o'clock for last. This will ensure that the weight of the valve does not leverage open the flange faces by its downward movement, as the bolts are removed. If the reverse occurs, that is, the flange begins to open from the bottom, it may be necessary to slack the load on the crane slightly to balance the flanges. A drift pin and maul may be necessary to drive out the last few bolts from their flange holes.

After all bolts are removed, bring the valve to the surface. Rinse it thoroughly with demineralized water as it exits the pool.

Upon reinstallation, suspend the valve by the lifting bridle in such a manner that the following occurs:

- Hang the valve body in such a manner that the flange face is in same vertical plane as the existing flange to which it will be mated. This will normally be completely vertical. A small plumb line may be helpful in assessing the vertical attitude of the existing flange face underwater, before rigging the valve for reinstallation.

- Suspend the valve body in such a way that the use of drift pins m aligning the bolt holes, or m the installation or tightening of the bolts, is not encumbered. Ensure at least half of the bolts and nuts are tightened, before loosening the lifting bridle assembly.

Lower the valve to the work site, where the diver will direct the positioning of the flange until he can insert drift pins between the two flanges. Do not install these drift pins in the top third of the flange bolt holes. This will leave room for the insertion of flange gasket or O-ring, later.

Insert bolts from about 9:00-3:00 o'clock, across the bottom of the flange. Place nuts on each bolt as it is installed. Do not run each nut on more than the width of the nut, leaving the flanges loosely apart. After this, the drift pins may be removed and the lifting bridle used to rock the flange faces sufficiently apart to insert the gasket or O-ring, if not previously installed. Insert the remainder of the bolts and tighten in accordance with the prescribed bolting pattern.

4.2. Fuel Transfer Assembly

4.2.1. Introduction

Repairs to the fuel transfer assembly fall into the following two categories:

- Faulty limit switches

- Disconnected drive systems

Limit switches control the range of motion of both the fuel transfer cart and the upender. When either fails to operate properly, the cart or upender does not stop at the desired point in the fuel transfer cycle and manual adjustment is necessary to complete the motion of the unit.

There are two different types of drive system designs used in fuel transfer systems. The first is the cable drive system which employs a cable connected to either end of the cart. The cable runs back along the tracks in both directions, to running sheaves which direct the cables vertically to winch drums. These are located on the surface, one in the reactor cavity area and the other in the spent fuel pool area. The second type of drive system uses a chain and sprocket drive.

Here, an air motor turns a master sprocket and chain, which in turn drives the cart.

Cable drive systems only require diver intervention when either the cart wheels jump the track, or when the cable is initially being retrieved through the transfer canal for connection to the cart. In this latter occurrence, a diver proceeds to the entrance of the transfer tunnel. Using an extension tool, he reaches through the tunnel and grasps the end connection of the cable to be connected to the cart. He then pulls it through the tunnel so that it can be connected to the cart. If the cart has jumped the tracks, it is due to one of the following reasons:

- The cart was "jerked" or placed in motion too abruptly, causing the wheels to jump the track.
- The wheel bearings are significantly worn, causing uneven weight distribution of the load to the wheels.

Chain and sprocket driven units usually suffer from a broken drive chain or a drive chain which has disengaged from the sprocket.

Likewise, the upender assembly usually fails to operate properly due to faulty limit switches regulating the movement of the basket containing the fuel bundle.

4.2.2. Equipment

The method of repair employed for faulty limit switches is to remove and replace the units. This is accomplished by a diver using a 12" adjustable wrench.

Similarly, the repair of a broken chain requires only a master link of the same size, and a pair of chain pliers.

If wheel bearings are worn and require replacement, tool requirements will depend on their exact design.

4.2.3. Procedures

As with any underwater pool operation, begin by vacuuming the pool area in the area near the work site. This is done to decontaminate the area in preparation for the work to begin. If the cart should break down with a fuel bundle on it, the bundle will have to be removed before repair operations can begin. A survey should be done to assess radiation levels in the area of the cart, and divers should only provide remote assistance.

To attach, or reattach, the pulling cable to the cart, the diver will require the use of an extension tool capable of reaching through the transfer canal and grasping the eyelet of the cable. Once in his control, the diver withdraws the extension tool until the cable has been brought through the canal. The diver then guides the eyelet to the pulling location of the cart and places the cable eyelet between the pulling padeyes and inserts the locking pin through them, fastening the cable in place.

To repair the limits switches, begin by preparing and sealing a new switch and cable of sufficient length on the surface. Locate the conduit for the electrical cable leading to the faulty switch. Have the diver descend with the new cable and switch, using the conduit as a guide, following it to the work site. Lower the new cable and switch with the diver, as he descends along the conduit.

After arriving at the location of the limit switch, confirm the location with diver to be sure he has arrived at the proper switch. The diver can then proceed to disconnect the old limit switch and install the new one in its place. As fasteners are being removed during this operation, they should be placed in a closed container until they are to be reinstalled.

Once the new switch has been installed, the equipment should be operated while the diver is still in the water, to determine that the repair has been a success. Before returning to the surface, the diver should take whatever steps directed to properly abandon the old conduit. As he ascends to the surface, the diver should use tie-wraps to secure the new limit switch cable to the old conduit.

If the transfer cart should jump its' tracks, the first requirement will be for the diver to properly reposition the cart upon the tracks. If the cart should happen to become untracked while in the transfer canal, make preparations to remove it before trying to correct the problem or inspect the cause. In this event, give the drive system first chance at extracting the cart from the canal, in the direction which represents the shortest distance to a clear overhead access.

If the cable or chain drive cannot extract the cart, use a surface lifting line which the diver can reeve it through a running sheave attached to a point in line, and at the same elevation. as the cart. This point should be at the other end of the pool in the intended direction of travel. This rigging arrangement will redirect the vertical lifting force into a lateral pulling force to the cart. Attach the end of the lifting line to either the cart pulling cable, or directly to the cart itself, using extension tools if necessary. In this fashion, extract the cart from the canal. If no suitable lifting point is available, consider attachment of the running sheave directly to the tracks themselves. Have the diver pay special attention to the rigging attached to the tracks be sure that excessive force does not damage the tracks.

After the cart has been extracted from the tunnel, attach a lifting line from the overhead crane to the cart, using a two-part bridle. Avoid any unexpected shifting of the load which might cause further problems. Slowly lift the derailed end of the cart and have the diver guide it back into position on the tracks.

After being reset on the tracks, inspect the cart for damage. Examine the wheels for signs of wear, such as worn bearings. If the cart requires immediate repairs, remove the fuel bundle from atop the cart before beginning any repairs. The exact repair sequence will depend upon the individual engineering design of the cart conveyance system.

Repair of the chain drive system will depend upon the type of problems encountered and the design of the system. If the chain has become disengaged from the sprocket on the cart, remove the retainer mechanism and reinstall the chain on the sprocket. If this occurs while the cart is in the transfer canal, extract the cart from the tunnel before beginning any repairs to the drive system. If the chain breaks, it may require installation of a section, or total chain replacement. Remove the cart from the transfer canal if required, and repair accordingly.

4.3. Torus and Suppression Pool Inspection

4.3.1 Introduction

Torus' in older BWR plants, as well as suppression pools in newer BWR's, require inspection on a periodic basis. During these inspections, look for signs of corrosion and coating damage which may have occurred. Conduct the inspection using personnel with special training as corrosion and coatings inspectors, or with divers carrying hand held video cameras. This will allow trained specialists at the dive station to monitor the condition of the torus of pool liner remotely. The torus or suppression pool is generally half full of water. The inspection consists primarily of a visual examination of the condition of the interior walls below the water line. Over time 'sludge' forms, covering the walls and bottom below the waterline. The thickness of this formation may range up to several inches in depth. Use an underwater vacuum to remove the sludge coating, to perform an accurate assessment of the surface condition.

In addition to a visual inspection, measure pitting caused by corrosion in areas representative of the general condition of the torus or pool liner. Measure areas of abnormally heavy pitting to assess the maximum corrosion existing. Check the thickness of the coating in random areas to assess its general condition.

4.3.2. Equipment

These inspections require the following, in addition to the normal diving equipment required:

- Underwater video camera and lighting.
- Underwater vaccuming system.
- Pit gauge.
- Handheld or helmet-mounted lights.
- Steel rule.
- Coating thickness probe.

The underwater video system should consist of a camera, video cable, underwater video light, video tape recorder, and monitor. Use a color camera to perform corrosion inspection. It will provide a representative view of the colors associated with the oxidation of metal. Corrosion inspection using underwater video also has special lighting requirements. Use a quartz-halogen light source to provide the best color representation for this type of inspection. Use a 150w light source for Inspections in the 1-3 foot range within the torus. Inspection ranges of 3-6 feet require at least a 250w light source to maintain color correctness. As with all video examinations, the video tape recorder used should be capable of pausing during the recording process. This allows the operator to edit an inspection report with reasonable continuity.

Use an underwater vacuuming system for removal of sludge and small debris. A complete discussion of underwater vacuuming equipment is provided in Chapter 3 of this guide.

Use a standard metal pit gauge to determine the depth of any pitting found to be occurring in the wall or down comers of the torus or suppression pool.

The diver may require a handheld or helmet-mounted auxiliary light to assist in inspection, should his video lighting source become inoperable.

A steel rule of some type, capable of both measurement and providing a representation of the size of anomalies found should be readily available to the diver. A standard retractable steel measuring tape works well for this purpose.

Use a thickness probe, of a type approved by the utility, to conduct periodic thickness measurements of the coating covering the wall of the torus. A non-destructive examination probe type is preferable to a mechanical type which penetrates the coating to determine thickness.

4.3.3. Procedures

Before beginning inspection, assemble all equipment and test in the following manner:

- Configure diving equipment and test in accordance with contractor operations guidelines, or guidelines provided in Chapter l of this guide.

- Assemble the video camera and check each connection to be sure of a positive contact. Connect a strain-relief line from the camera to the video cable leading to the recorder. This will relieve any strain which might otherwise be placed on the electrical connector. Operate the camera to be sure that it is producing an acceptable picture quality on the monitor. Make preliminary adjustments to the monitor to enhance picture quality. The video recorder footage counter should be reset to read zero.

- Check video lights to be sure that they work. Supply power for not more than 5 seconds. Durations longer than this, out of water, may cause the bulb to overheat and fail.

- Test the underwater vacuuming system in accordance with guidelines provided by the manufacturer, or in Chapter 3 of this guide.

- Examine the pit gauge to be used, and determine that it is in good operating condition and easily legible.

- Examine the thickness gauge to be used, and test underwater upon a metal of known thickness. Calibrate if necessary.

- Examine the steel rule to be sure that its markings are read easily. If a retractable tape is used, test the mechanism to be sure that it works.

To begin the inspection operations, open the hatchway leading into the area at the point selected as the starting point. Inspect the existing ladder, if any, for suitability. If a ladder does not exist, use the ladder from the diving equipment package, attaching securely.

Perform a preliminary examination of the immediate area near the point of entry. If this area indicates that cleaning is required, use underwater vacuuming equipment to desludge the area before attempting the inspection. Then proceed with the inspection and testing of the desludged areas.

For torus inspections, deploy the underwater vacuum system at each hatchway around the torus. Provide enough suction hose to allow the diver to vacuum at least one half the distance to the next hatchway opening in each direction. Vacuum in slow deliberate sweeps, from the 9:00 - 6:00 o'clock position, to the length of its suction hose. Returning, vacuum from 3:00-6:00 o'clock in the opposite direction. In this manner, by moving the vacuuming system from hatchway to hatchway, the entire torus can be desludged with maximum efficiency.

After completion of the desludging, remove the vacuuming system and deploy the video system. For torus inspections, use the video to scan a path extending from 9:00-6:00 o'clock and continuing up to 3:00 o'clock, and then reversing the procedure to return to the 9:00 o'clock position. With each completed cycle, advance around the torus proceeding with the inspection. Never allow the diver to proceed more than one-half the circumference of the torus, due to the potential for complications to arise, in the event of an emergency.

As the diver progresses through the video inspection, instruct him to perform pit gauge testing or coating thickness evaluations as required. Record measurements taken in the inspection log, noting the corresponding video footage counter reading, and describing their location on the torus or suppression pool liner.

4.4. Spent Fuel Pool Reracking

4.4.1. Introduction

To accommodate the requirements for extra storage of spent fuel, utilities have found the need to increase the density of the spent fuel bundles stored in their spent fuel storage pools. This solution requires the removal and reinstallation of new, higher density racks to accommodate the new fuel bundle configurations.

The entire process is subdivided into three major activities or phases:

- Removal of existing racks
- Preparation of the pool for receipt of the new racks
- Installation of the new racks

Remove existing racks by shifting the stored fuel to racks on one side of the pool. Begin removing racks on the opposite side by locating their attachment points. To prepare for the pool for removal of the old racks, all fasteners, brackets, and seismic supports must be removed. Vacuum the pool bottom thoroughly to remove all debris resulting from the cutting operations.

Installation of the new racks requires that new seismic supports or pads be installed where applicable, then lowering of the racks themselves, and leveling into position. Unless the new racks are of a free-standing design, they may require final fastening to the pool liner to form a monolithic unit.

4.4.2. Equipment

The equipment required for phase 1 of the reracking project consists of

- Underwater vacuuming.
- Underwater cutting equipment.
- Waterblasting [hydrolasing] equipment.
- Overhead crane and lifting bridles.

The underwater vacuuming equipment is used to decontaminate the work areas, before diver access. The use of this equipment is detailed in Chapter 3 of this guide.

Underwater cutting equipment is used to sever the fasteners which hold the racks in place. They must be cut tolerances specified by the client. The type of equipment used for these cutting operations is determined by

- the physical location of each piece of metal to be cut.
- the requirements for the precision of the cut.
- the configuration of the material.

A 10,000 psi waterblasting system is used for decontamination of the old racks before removing them from the pool. Instead of the traditional gun-type end-effector, the high pressure water hose is connected to a trigger valve at the end of a 16 straight section of high pressure piping. The piping is fitted with a conventional waterblasting nozzle at its end. This allows the nozzle to be extended the full length into each of the rack divisions, to remove any contaminants which might have accumulated on the interior surfaces.

Chapter 3 provides a complete discussion of underwater cutting, vacuuming, and waterblasting equipment.

Underwater vacuuming equipment is once again used to vacuum the entire pool before beginning the installation of the new racks.

Equipment required for phase 3 will consist of the following items:

- Overhead crane and a lifting bridle
- Surveying level and graduated pole

- Hydraulic jack
- T-bar rack leveling tool
- Steel tape measure/wax pencil

The overhead crane and lifting bridle assembly are used to install the new racks in the pool. As always, fabricate the lifting bridle in such a way as to suspend the rack in a vertical and level attitude.

Use a surveying level and graduated pole to level the new rack to a vertical attitude, before deployment in the pool. The same tools are again used after the rack has been deployed, to be sure that its vertical position is within warranty specifications.

A hydraulic jack, such as a 'porta-pak' system, capable of lifting one side of each new spent fuel rack, is required. This tool is used to level the rack legs after installation in the pool. The jack should be capable of easy positioning by the diver, and the lifting surface should be capable of insertion within the space available between the bottom of the rack and the liner pad.

A T-bar type device long enough to be inserted down the new fuel rack, to reach the leg adjustment, is required. The T-handle on top of the device provides the diver with a means of turning the adjustment, and engaging the leveling foot on the rack.

A steel tape measure is required to determine the exact position of the support pads on the pool liner floor. These pads distribute the weight of the new racks evenly over a large portion of the floor. Use a wax marking pencil to scribe the pad positions on the floor of the pool.

4.4.3. Procedures

As with any pool operation conducted underwater, vacuum the area near the work site to decontaminate the area, in preparation for the work to begin.

Locate all attachment points which connect the existing racks to either the bottom or sides of the spent fuel pool. Verify their positions as indicated on drawings.

Select and appropriate cutting tool for severing these points. Make all cuts as closely as possible to the walls or floor of the liner, to reduce the amount of cutting or grinding necessary later. Before each cut, have the diver describe and verify the location with the diving supervisor. After making each cut, mark that location as completed, on the pool drawing.

Any points, such as seismic supports existing on the bottom of racks, not readily accessible during the removal operations, must be 'tunneled' to, and severed. Do this using an appropriate cutting instrument, such as an arc-water gouge, and rough-cutting existing fuel rack members, removing them one at a time, as the diver works his way towards the attachment point to be cut.

Before removing a rack from the pool, be sure that all attachment points have been severed, and that nothing exists which might cause the rack to 'hang up' as it is being lifted. This might cause damage to the pool liner. Attach the lifting bridle, hanging from the overhead crane block, to lifting points on the rack. Verify that the lifting device is properly engaged. While some rack designs can be lifted from the top, others must be lifted from points on the bottom of the rack. In actually removing a rack, it may be necessary to have more than one diver in the pool at one time. Position each diver at a top corner of the rack, located diagonally across from each other. Take a strain on the load line of the crane, and lift the rack is gently off the bottom of the pool. Move the rack away from the adjacent racks, while lifting it to the surface. The rack movements should follow a pre-planned safe load path.

Once the rack is free to come to the surface, have the divers exit the pool before the rack is hydrolased. Complete this before the rack is lifted out of the water. The divers may then re-enter the water and repeat the process with another rack section. until all open racks are removed.

Once a portion of the pool has been cleared of old racks, inspect the pool and cut or grind the remainder of the old fasteners flush with the pool liner. This is especially important on the bottom of the pool, where pads to distribute the weight of the new rack will be placed. They must not rest on any high spots which would create pressure points. Vacuum the open pool area to remove any debris which has gathered on the bottom during prior operations.

Once thoroughly cleaned, begin installation of the new racks in an open corner of the pool. Begin by determining the exact location of the support pads for the first rack, on the pool floor. Give the diver the plate size and orientation for each location. Use a steel tape measure and wax pencil to measure and mark out the position of each pad on the liner floor.

Attach the pad to the lifting bridles connected to the overhead crane, and lower into the water. Have the diver meet the pad off bottom, and guide the pad to within about 1 foot of the bottom. Orient and position the pad in accordance to the wax pencil markings, before lowering the pad to the floor of the pool. If a weld seam in the liner floor exists, and the pad has been specially fabricated to allow for that seam, check to be sure that the pad is properly positioned with respect to the weld, before removing the lifting bridles.

From this plate, measure and plot the location for the next pad, and mark its position on the floor as before. Install successive pads in a like manner. After all pads allotted for the available floor space have been positioned, begin the installation of new racks.

Position the first rack in an open corner of the pool, with successive racks built out from there. Level the rack using the surveyors level and pole, and attach the crane and lifting bridle. After it has been leveled on deck, lift the rack and place it in the pool, in an open area and slowly maneuver to its general deployment area. Do this without divers in the pool, to prevent injury to the divers during the gross movement of the rack.

Use two divers for final positioning of the rack. Locate one diver on either side of the rack, to provide constant visual surveillance as the rack is lowered into final position. Rely on guidance from the divers to carefully move the rack to within 1 foot of the bottom of the pool, and then laterally into its final x-y position. Carefully measure the position of the first rack, as all future rack placements will reference from this rack location. When satisfied, lower the rack onto the load pads positioned on the pool floor.

Instruct the divers to place the tip of the surveyors pole atop each corner of the rack, and hold in place in a vertical position. Use the level to comparing 'sightings' on that portion of the pole extending above the waterline, as the pole is moved to each corner of the rack.

If the rack is out of vertical alignment, to an extent which would either impact the installation of later racks, or void the spent fuel warranty, then one diver will maintain the pole position atop that side of the rack requiring adjustment, while the second diver, using a portable hydraulic jack placed underneath that side/corner of the rack, adjusts the vertical attitude of the rack. Then insert the T-bar adjustment probe down through the rack and engage the adjustment leg. Turn the T-bar to extend or retract the adjusting foot as necessary.

Certify that the rack is in the proper position, and within required tolerances. Remove the lifting bridles and all tools from the pool. Repeat this process until all available pool space is filled with new racks.

As old racks are removed and new racks installed, the operation progresses across the pool. At some point, discontinue the reracking operations and transfer spent fuel bundles from their existing locations to the new racks. Once this fuel transfer is completed, continue with the remainder of reracking operations.

4.5. Pool Liner Repair

4.5.1. Introduction

Occasionally, pool liners develop leaks which require repair. These leaks result from either a mechanical perforation of the pool liner, or the failure of a liner seam weld. In the former case, a leak in the floor of the liner suggests a dropped object in the pool. A wall leak would be less frequent, and would probably only occur during the movement of large loads close to the pool wall. Conversely, if an object contacts the pool liner during its movement in the pool, it is good operating practice to note the exact location of contact in the operations log and perform a visual inspection of the area as soon as possible. Weld seam failure, on the other hand, is almost always due to Intragranular Stress Corrosion Cracking (IGSCC), and is difficult to locate. At present, the most common method for leak detection in the pool liners uses a vacuum box detection system. This system is manually operated by the diver.

There are the two repair alternatives presently available, depending upon the severity of the leak, and whether the repair is to meet the criteria for a temporary or permanent repair:

- Surface epoxy application
- Patch welding

In the application of a surface epoxy, such as 'Splashzone'-brand by NAPCO, the repair is obviously of a temporary nature, and is itself subject to leakage over time.

Stainless steel patch welding is the only permanent type of repair. It may consist of either welding a flat plate or pipe cap over the leak area. While the stainless plate might seem most appropriate, a pipe cap welded over the leak can contain a test port. To do this, tap a fitting into the cap, and attach a helium supply pressure line or vacuum hose. The pipecap weld can now be leak tested by either pressure containment or evacuation before completing the repair.

4.5.2. Equipment

The equipment required for leak detection consists of the following:

- vacuum boxes
- vacuum pump and hose
- divers stage
- wax pencil

An assortment of three vacuum boxes specifically designed to accommodate different areas are required. They should include a long vacuum box designed for weld seam inspections, a radius curve box designed to accommodate the pool wall to floor transition curvature, and a square plate box for inspection of flat portions of pool wall and flooring. Typically, the boxes are constructed of clear acrylic with a sealing surface around the facing edge, and an evacuation port on top.

The vacuum pump and hose used are standard evacuation equipment, and should be capable of sustaining a minimum vacuum equal to 18" of mercury.

Because of the sustained duration required for vacuum leak testing and repair operations, use a divers stage to support the diver on vertical wall welds and surfaces. A boatswains chair is also suitable for this type of service.

Use a wax pencil to mark each area as it is tested, to provide a visual reference to be sure of overlapping testing. Mark each area as it is completed. Use the pencil to pinpoint the exact location of the leak, once it is found.

If a temporary repair using a surface epoxy is to be used, the following items will be required to support operations:

- Mixing vessel and spatula
- Rope
- Transfer vessel
- Patch plate

Use a wide-mouthed vessel half filled with water, such as a bucket, and a spatula, to mix the epoxy.

A length of 1/4" polypropylene rope of long enough to extend from the surface to the repair site, may be needed to deploy the patch plate and epoxy.

A transfer vessel, such as a bucket, large enough to carry the plate and epoxy, is required. The mixing bucket may be used for this purpose.
The patch plate consists of a piece of stainless steel whose perimeter is at least two inches from the edge of the leak to be repaired in all directions.

The equipment necessary for a permanent welded repair includes

- Underwater wet welding equipment
- Vacuum pump and hose
- Stainless plate or pipe cap

The underwater welding equipment requirements are discussed in detail in the section on underwater wet welding, located in Chapter 3 of this guide. The vacuum pump and repair materials have been previously described.

4.5.3. Procedures

Vacuum the pool area in near the work site to decontaminate the area in preparation for work to begin. Do this by first cleaning a base area from the surface from which the diver can work to complete the cleaning.
In preparing to locate the leak, if a probable area cannot be determined, examine the entire pool. Small leaks are associated with welds seam failure, while higher volume leakage is more likely caused by a penetration of the liner walls or flooring.

Before beginning diving operations, check all pool areas which are accessible from the surface, using a vacuum box and extension tools. Test the vacuum box at the surface, to be sure of its proper operation, before beginning pool testing.

In order for the diver to perform a leak test using a vacuum box, take the following steps:

- Position the vacuum box by marking a starting point for the box on the liner, using a wax pencil. On a weld seam inspection, this will be a lateral mark across the weld seam. On the liner itself, make two marks, one at each corner on one side.
- Position the vacuum box over the area to be tested and supply air to the box to displace any water which might be contained m the hose or box. It is necessary to discharge the water m this manner, as any water m the system will affect the accuracy of the vacuum gauge.
- After forcing all the water out of the system with compressed air, shift over to the evacuation process. The diver will signal when a vacuum has been placed on the box, as indicated by his inability to move the box.
- Continue the evacuation of the box until the vacuum gauge reaches about 18" of mercury. Begin a two minute test to determine whether any leakage is occurring. While this is in progress, mark the position of the other end/side of the vacuum box, so that the area tested is shown. Where the area tested is a square section of liner, place an 'X' m the middle of the tested area after removing the box.

- After completing the test, if no leak is found, equalize the system from the surface, and reposition the vacuum box to an adjacent position. Overlap the end-markings previously inscribed with the wax pencil, to be sure that the tested areas overlap. Continue to repeat the testing m this fashion until the leak is found.

- When a leak is found within the test area, perform a visual inspection to locate the leak. If this is not successful, position the vacuum box over half of the previous test area, and retest. Continue to halve the area under scrutiny until the leak site is reduced to a minimum size for subsequent patching. This is usually 2"-3" in diameter.

If a temporary epoxy seal is to be used, take the following steps:

- Fabricate a stainless steel plate of large enough in diameter to encompass the leak area with a minimum 2" border in all directions.

- Mix the two-part epoxy according to manufacturers specifications for underwater use, using the mixing vessel and spatula. In the absence of other instructions, use a 50/50 mixture of epoxy base and converter catalyst. The mixture should harden to the touch within 20-25 minutes, depending upon water temperature. Adding additional converter to the base compound will speed hardening time accordingly.

- Form an appropriate amount of epoxy into a ball and place m the center of the patch. The amount of epoxy used will depend upon the size of the patch to be covered when the epoxy is flattened out during patch application.

- Transfer the plate and epoxy patch to the transfer vessel and lower by rope to the diver.

- Place the epoxy side down over the leak area, and press upon the back side of the plate. This will flatten the epoxy out between the plate and the liner. Press until the epoxy reaches the edge of the patch on all sides.

If a permanent repair is to be performed, take the following steps:

- Determine the type of repair, whether a flat plate or pipe cap, and qualify the appropriate welding procedure and personnel, according to those criteria outlined in Chapter 3, on underwater welding.

- Configure the welding equipment and test in accordance with contractor procedures. In the absence of other guidelines, use those suggested minimum procedures outlined in Chapter 3 of this guide.

- If the leak is in a weld seam, grind the seam flush enough to produce an acceptable fit up for the repair method to be used.

- Prepare a plate or pipe cap large enough for use as a patch. If a plate is to be used, finish its edges for a filet weld. If a pipe cap is used, bore a hole m the top of the cap and thread an appropriate fitting into the hole.

This will allow the acceptance of a pressurization hose, for later testing purposes.

- In both cases, tack a grounding terminal to either the plate or cap, to provide an attachment point for the grounding cable. Remove this terminal after completion of the weld.

- If the repair is on a vertical wall, position a vaccum hose with a wide suction nozzle below the weld area to catch any slag or debris which may form during the repair process.

- Position the repair patch over the marked area identifying the leak, and while holding the patch in position, tack the patch into place.

- Complete the welded repair in accordance with the welding procedure specified.

- Once completed, inspect the plane weld before concluding operations. If a pipe cap has been used in preparation for testing purposes, install the test hose and perform the test. Upon completion of the test, remove the test fitting and install a threaded plug m the cap. Tighten this plug to its end limit.

4.6. Circulating Water Intake Inspection

4.6.1. Introduction

The circulating water system intakes require periodic inspection to be sure that restrictions are not developing and that adequate water flow is maintained to the plant. This inspection is normally performed by divers, although ROV's are used for facets of this work.

The purpose of the inspection is to assess the amount of debris which has gathered, its location, and to remove it as cost-effectively as possible. Plants with intakes in certain areas, such as on lakes and ponds, may also experience a problem with specific marine organisms.

The Zebra mussel is one organism that multiplies at an extremely rapid pace. It often requires plants suffering infestation to inspect and remove them several times a year, to maintain adequate circulating water flow. In this specific case, chlorine injection and other forms of prevention have been tried without significant success. Latest studies indicate that Zebra mussels are highly sensitive to heat, and that only a one minute exposure to water temperatures greater than 170°F will effectively kill more that 95% of the organisms present. This can be done by back-washing high temperature water from the plant, through the intakes, during an outage.

Plants with river intake experience problems centered more in the area of advanced sedimentation and debris accumulation. These problems stem from the top soil and debris washed downstream by the flow of the river.

Oceanside plants also experience problems in the area of marine growth, though from salt water organisms. These plants are also particularly susceptible to advanced corrosion of the steel components of their intake structures, due to the salt water environment. They also have some maintenance requirements stemming from debris accumulation at intakes.

The following items in the circulating water system intakes are inspected periodically, unless individual conditions have shown that more frequent inspection is required:

- Intake area
- Intake rack
- Traveling water screens
- Intake pump
- Intake tunnel

The intake area, or intake basin as some refer to it, is that area immediately outside of the intake openings from which the water for the circulating water system is drawn This area may be particularly prone to debris accumulation, due to its proximity to the shoreline. For riverside plants suffering from advanced sedimentation, it is particularly important to establish the rate of sedimentation so that periodic dredging can be scheduled. In moving water systems such as rivers and the ocean, this area should always be monitored for excessive accumulation of debris which could suddenly shift. This would present the possibility of blockage of the intakes.

The intake rack is designed to provide the initial screening mechanism for stopping debris from entering the circulating water system. These racks are vertical bars which act as a barrier to larger debris, and must be inspected and cleaned periodically. They also act as a base for marine growth, and as such must be cleaned of these organisms as necessary.

The traveling water screens are located between the debris racks and the intake pump. The pump circulates the water through the plant cooling system. These traveling screens were designed as a self-cleaning barrier to smaller debris which might otherwise damage the impeller on the intake pump, or block piping in the plant. In practice, these also require periodic inspection and cleaning to remove lodged debris and marine growth which may have accumulated.

The intake pump is located directly behind the traveling water screens. It requires inspection of its intake housing and impeller for signs of corrosion and wear. Because of its configuration, only the intake bell housing and the leading edge of the impeller blades may be inspected, due to restricted access.

The intake tunnel, covering that distance from the pump to the plant itself, may or may not be inspected, according to individual plant requirements. Normally, only a slight degree of sedimentation is found in this area, due to the high flow rates which occur in the tunnel. Occasionally, the wall of the tunnel itself may require inspection for corrosion or stress cracking, depending upon whether it is constructed of metal or concrete, respectively.

4.6.2. Equipment

The equipment required for the inspection of the circulating water system varies according to the extent to which the system and its components will be inspected. The method of inspection, whether by diver or ROV, also affects the equipment requirements. However, assuming a complete diver inspection of the system, the following equipment will be required, in addition to the diving equipment necessary to support operations:

- Waterblasting system
- Lifting equipment
- trash pump
- Wide-blade hand scraper
- Micrometer
- Handheld or helmet-mounted lights
- Pitting gauge

The waterblasting equipment required for the cleaning of the intake structures should be a minimum 10,000 psi unit. Both conical and fan nozzle tips should be available to meet various cleaning requirements. A complete discussion of waterblasting equipment is provided in Chapter 3 of this guide.

A suction, or trash pump, as it is called, is required to remove the debris which results from the cleaning of both the screen and pump houses. Use a 6" diameter intake pump to achieve the highest rate of debris removal, while still allowing a diver to easily and safely control the suction hose end. While slightly smaller pumps might be used, they are prone to congestion when removing large quantities of solid materials.

Depending upon the extent and type of debris to be removed from the intake canal basin, some form of lifting equipment may be required to assist the diver in this operation. Smaller debris which has accumulated near the face of the intake racks can be manually loaded by the diver onto the rack cleaning rakes. It can then be removed in that fashion. Debris which cannot be removed in this matter must be either deposited in a large salvage basket lowered to bottom by a boom and winch, or attached directly to a load line from the surface. This is required for large debris items.

Wide-blade hand scrapers are extremely effective for the manual removal of marine growth from the walls and floors of the screen and pump houses, and any other flat areas found in need of cleaning.

Use of a micrometer may be required to measure the thickness of the impeller blade at representative points to determine the condition of the blade with respect to corrosion. The micrometer should have a gap large enough to fit over the impeller blade width.

Use handheld or helmet-mounted underwater lights to inspect the intake structures. If battery operated, the diver should carry an auxiliary light as a back-up in case the primary light suffers a bulb failure or battery drainage during the dive.

Use a pitting gauge to measure representative areas of corrosion found in the walls of metal pipes and intakes structures.

If the inspection is to be done using an ROV, the operations will be limited to a visual and cathodic inspection, unless there is a point of access large enough to accommodate a work platform ROV carrying waterblasting and dredging equipment.

Minimum requirements for an ROV visual inspection would include a vehicle equipped with a low-light camera system, variable intensity lighting of at least 150w, and capable of maintaining position in local current conditions. If corrosion inspection is to be done, a color camera system, quartz-halogen lighting sources, and cathodic protection probes are required. The color camera and special lighting provide the necessary color spectrum references for corrosion analysis by corrosion engineers.

4.6.3. Procedures

Because of the high rate of flow associated with circulating water systems at nuclear plants, perform underwater work in these areas with a great caution. While many diving contractors routinely perform maintenance tasks on intake structures ahead of the traveling screens, with the intake pumps running, the potential safety risks to the diver and resultant liability exposure to the utility make this practice somewhat questionable. Although many of these tasks are performed without incident, the high rate of localized flow at the intakes, combined with moving equipment in poor to nonexistent visibility, significantly reduce the margin for error in these diving operations. If a diver were to become fouled and experience equipment failure, he might very well be unable to self-rescue under these conditions with the same degree of success possible in a static water system. It is also unlikely that a diver can perform either inspection or cleaning operations with the same degree of efficiency possible under less demanding conditions.

For these reasons, it is good operating procedure to tag out of service, those intake pumps where diving operations are to be performed. This should be done by the maintenance person in charge of the diving operations, and witnessed by the diving supervisor. If possible, locking down the pump control switch is the preferable alternative. In any case, maintain a direct line of communication between the intake system dive station and the pump control switch location. Do this before beginning diving operations. Maintain this communications link until all diving is completed, and the pump is tagged back into service.

Begin the actual inspection of the intake structures with the intake canal basin and debris racks. Assemble and test all equipment at the dive station. Then, locate a safe and secure means for the diver to enter and exit the water. Do this by installing a diving ladder fastened securely at the point of entry. To be sure of the tenders' safety, while tending the divers' umbilical at the waters edge, require that he wear some form of U. S. Coast Guard approved personal flotation device. If diving operations are to be conducted while intake pumps are running, connect the tender to some type of hold back line which is securely fastened to a surface structure. This will prevent his being accidentally pulled into the water, should the divers' umbilical accidentally get jerked in his hands.

Before beginning the inspection of the intake canal and debris racks, ask the diver and his tender to demonstrate their knowledge of the work tasks to be done. Review the areas to be inspected with the diver and the diving supervisor, before allowing the diver to enter the water.

Upon entering the water, the diver should maintain an awareness of his umbilical position and its direction of travel. Likewise, the divers' tender should maintain a close control over the amount of slack which he allows to enter the water, and should report any deviations from the expected umbilical position immediately to the diving supervisor.

Begin the inspection by working down one of the vertical debris rack bars until to the bottom. Check the immediate area for accumulated debris. Move a set distance laterally and begin inspecting the adjacent area of the debris racks, while ascending to the surface. If the pumps are running while these operations are taking place, remind the diver to keep his umbilical running horizontally across the bars of the debris rack. This will prevent its becoming pulled through the bars, into the screen house. Continue this serpentine inspection pattern of ascending and descending paths until the diver has worked his way across the entire debris rack.

During this inspection of the debris racks, determine the location of any debris lodged in the racks which cannot be recovered using the conventional rakes. Note the general condition of the racks, and the amount of marine growth covering them, if any. If the racks are to be waterblasted to remove marine growth, do this after the initial inspection is completed, using the previously described pattern.

To remove large debris from the intake area, use a crane line or winch line from a davit on the surface. Recover smaller debris in the general area by manually picking it up and placing it into the rack rake for routine recovery. If the diver is using a lifting line from the surface, follow these guidelines for safe recovery:

- Shackle a minimum 20' long sling choker into the lifting block of the crane, extending downward and providing the diver with a safe distance from the lifting block with which to work.

- Attach a screw-pin type shackle to the working end eyelet of the sling for the divers' convenience m attaching the choker to the object to be retrieved.

- Establish a downline, consisting of 1/2" rope, from the surface to a point on bottom which will remain easily locatable for the diver, and out of the way during operations. Shackle the lifting line on a running shackle to this line, and use this to guide the lifting sling back and forth to the diver as required.

- When attaching the lifting sling to the object to be recovered, pass the end of the sling around the object and shackle the eyelet back into the standing part of the sling. Attach the sling at a point which, when the sling tightens around the object, it will become securely attached. The diver should take care that, particularly in water with poor visibility, he not shackle his diving umbilical into the lifting sling, thereby potentially cutting of his air supply and fouling him on bottom as the sling tightens around the object.

- When the diver signals the topside personnel to begin coming up on the lifting line, take the slack in the line up very slowly. Have the diver monitor the closing loop of the sling around the object to be sure that the object becomes securely slung. Otherwise, the object may accidentally fall while being lifted.

- When the diver signals that the all the slack has been taken out of the lifting line, and the object is securely fastened, stop the lifting process until the diver repositions himself and his umbilical to a point of safety. As the load is raised from the bottom, shift the topside lifting point away from the diver. As the object leaves the bottom, it will tend to swing naturally in the opposite direction from the diver, as a result.

- Once the object is safely on the surface, instruct the diver to return to the base of the downline and await the returning lifting line. After receiving the lift line, have the diver attach it to the next object to be recovered. Continue this until all objects have been recovered from the bottom.

If there is not enough visibility for the diver to see the area in question, use the face of the intake structure as a reference point. Starting at one end, work down the face of the structure and return along a path a few feet out from the structure. By increasing the distance from the structure with each pass, the diver will accomplish a relatively complete survey of the area.

To examine the traveling water screens, descend a ladder into the screen house through a surface hatchway. Assess the condition of the screens and any marine growth found. Check the position of each anode on the screens, and measure its size. Gauge its average pitting depth to estimate its percentage of depletion.

Using a wide-bladed hand scraper, or waterblaster, clean the walls of the screen house of any build up resulting from marine growth. Begin the cleaning around the bottom of the area and work upward. Debris cleaned from the walls tends to gather on the floor, impeding later cleaning progress in that area.

Complete cleaning operations and deploy a trash pump to suction up all of the accumulated debris from the cleaning operations. Locate the pump discharge in an appropriate area downstream of the work area. If desired, conduct the same cleaning operations in the pump house.

In examining the pump, check for the following items:

- the level of depletion of the sacrificial anode attached to the bell housing of the impeller.

- the amount of marine growth existing on the impeller housing and impeller blades.

- any pitting of the impeller blade.

To assess the level of depletion of the sacrificial anode, determine the original size of the anode. Measure the existing size of the anode, and using a pitting gauge, estimate the average depth of pitting on the surface of the anode. From this information, calculate the percentage of total depletion. Compare this to the previous inspection to calculate the approximate rate of depletion since the last inspection.

Estimate the amount of marine growth occurring on the impeller blades and internal housing. Check the ends of the impeller blades to determine if they, or their marine growth, has been contacting the inside of the impeller housing. This could result in a wear pattern on its inside surface. If a wear pattern exists, yet marine growth is light, this indicates worn bearings supporting the impeller shaft.

After cleaning the impeller, use a micrometer to determine the level of pitting on each impeller blade. This pitting will be greatest on their leading edges. Check the leading edge of each blade for chipped areas, as well as the blade tips. Check the base of each blade, where it attaches to the impeller hub for signs of stress cracking.

To inspect the intake tunnel, enter a separate hatchway downstream of the pump house, and proceed from there towards the plant. Inspect representative areas of the tunnel wall for pitting or cracking, and note their location. Do not allow the diver to travel more than 300 feet laterally into the tunnel, without an auxiliary breathing gas supply sufficient to return him to the point of entry.

4.7. Spray Pond Inspections

4.7.1. Introduction

Spray ponds used to cool water circulated through the heat exchangers have several unique requirements for underwater inspection and maintenance. The system consists of a large pond which contains a network of piping and nozzle assemblies which direct heated water to be discharged into the pond upwards into the air in a spray pattern. It cools as the spray falls, and collects in the pond.

Within this system, there are several items to inspect, including the following:

- Piping and support structures
- Nozzle assemblies
- Sacrificial anodes
- Intake screens

The piping system used in the spray ponds consists of a series of pipes supplied from a central header, with upward-directed spray nozzles at various locations. The piping is generally on supports and attached by brackets. Inspect all piping, as well as the fastening brackets, for signs of corrosion on a periodic basis.

Likewise, inspect the nozzle assemblies for signs of corrosion. Blockage to individual nozzle ports may occur from the accumulation of debris in the system.

These various nozzle problems are easy to spot as irregularities in the normal spray pattern

Sacrificial anodes are attached at various locations to the spray pond piping. Each of these anodes requires that its location be confirmed and its percentage of depletion estimated. Do this by measuring the anode and the average pitting of its surface. When compared to past inspection data, this information is used to calculate the rate of depletion. Replace anodes which are depleted.

Inspect the intakes of the spray pond which are fitted with intake screens. Clean these of any debris or sedimentation which might pose a potential restriction to the system.

4.7.2. Equipment

Beyond the standard array of diving equipment, there are only a few pieces of additional equipment necessary for spray pond maintenance. These include

- Hacksaw
- Adjustable wrench/air impact wrench
- Pit gauge
- Cathodic potential probe

Remove the anode brackets of anodes which have become depleted to lessen the cathodic potential load placed upon cathodic protection system. Use a hacksaw to cut the bolts holding the brackets to the piping, and remove the bracket from the pond.

To install new anodes in the system, use an adjustable wrench to tighten the bolts of the anode brackets upon installation. There should be a screw-down contact pin which provides electrical continuity to the installation. Tighten it until its point firmly contacts the piping. If several anode retrofits are required, use an air impact wrench to improve the speed and cost-effectiveness of the operation.

Use a pitting gauge to check the corrosion which has already occurred in the piping. Measure representative areas for comparison with previous surveys.

Use a cathodic potential (CP) probe, based on a silver/silver chloride (Ag/AgCl) reference cell, to determine the cathodic potential in the pond. A low reading, according to the reference, shows good protection and an adequate cathodic protection system in place. A higher reference reading shows that excess metallic debris in the pond should be collected and removed, and that additional anode installations are warranted.

4.7.3. Procedures

To inspect the spray pond system, develop a plan for the comprehensive inspection to be sure that 100% to of the anode locations are checked, and a representative number of corrosion pitting inspections are made. If required, plan to take cathodic potential readings Inspect the spray pond supply header and the general condition of all other piping and nozzles. The general inspection is most easily accomplished as part of the anode location and cathodic potential survey.

Instruct the diver to complete a cathodic potential survey, using a hand-held cathodic potential probe, during his visual inspection of the system. Readings should be taken at regular spaces over the entire piping system. This is done by placing the probe in contact with the piping while a CP reading is read from the meter, located the dive station. Log each reading in the inspection notes. In any areas where obvious shielding or 'shadowing' of the piping from the anodes occurs, take a CP reading to determine the cathodic potential in that area.

Verify each recorded anode location and estimate its percentage of depletion. Check that the continuity bolt is solidly in contact with the piping, and that the anode fasteners remain secure and in good condition. Record these items in the inspection log for future comparison.

To retrofit a bracelet-type anode, arrange to transport the anode to the installation site. The manner is largely dependent upon the individual design of the pond and piping system, and the size of the anode. Once on location, position the anode over the top of the piping, and attach the bracket brought underneath the piping. Bolt the anode to the piping using a wrench or air impact wrench. Check that all bolts are securely fastened, and that the continuity bolt is tightened until its point has penetrated the existing pipe coating and securely contacts the bare metal of the pipe. This provides electrical continuity for the anode to the system.

Perform a visual inspection of the piping and nozzles, noting any apparent anomalies in the system, or obstructions to the nozzle ports. A hand probe, such as a long-bladed screwdriver, makes an excellent tool for probing nozzle ports for debris.

Survey the intake area for sedimentation and inspect the screens for any debris which might be impeding the flow of water from the pond. Remove all debris possible from the pond. If sedimentation around the intakes appears to present an existing or potential problem, use a 4"-6" trash pump to remove the sedimentation from the immediate area and redeposit it elsewhere.

4.8. Welded Repair of Feedwater Spargers

4.8.1. Introduction

Feedwater sparger pipe and nozzles may suffer damage due to the action of foreign objects lodged in the nozzles. Over time, this can result in the perforation of the nozzles through friction caused by the flow-induced movement of the objects. In seeking to repair such damage, begin by determining the following information:

- exact cause of the system damage.
- number of components of the system involved.
- extent to which each component is damaged.
- potential for additional damage to occur.
- radiation levels in the immediate work area.
- existence of loose parts resulting from the damage.

Given this information, it becomes possible to develop a scope of work which will reflect the most safe, efficient, and cost-effective method of repair. Gathering this information requires a preliminary visual inspection of the area, and is well suited to either the capabilities of a diver or an ROV. In either case, use a high-definition video camera fed to a surface video cassette recorder to document the inspection. If an ROV is used, be sure that it is also equipped with

- depth sensor.
- dimensional rule visible to the ROV camera, providing topside personnel with an indication of size and distance relationships in the damage area.
- remote-reading dosimeter to check the radiation levels in the work area.
- manipulator, if loose parts or foreign object retrieval is to be attempted.

The next step is to remove the cause of the damage. Do this as soon as possible, to prevent further damage from occurring to the sparger pipe or nozzles. In this same effort, recover any loose pieces of material from the damaged area to prevent their accidental distribution to other parts of the system.

In selecting a repair option, attempt to answer the following questions:

- Is a repair of the system necessary?
- Does the repair need to meet original specifications for the system?
- If not, what alternative repair options exist which will provide a workable solution to the problem?

Keep in mind when developing the scope of work, to seek a level of repair will achieve an acceptable solution to the problem. It is not always necessary to select a repair option which attempts to return a system to its original specifications.

This point is well illustrated by one instance at a utility where only two (2) nozzles were damaged, and the sparger pipe remained virtually intact. It was determined from the manufacturer that the utility could safely and efficiently operate the reactor with two less nozzles in place. This type of preliminary investigation radically altered the repair scenario for both the utility and contractor, taking it from one of difficult nozzle replacement to a less complicated nozzle plugging operation.

In proceeding with a welded repair of the above type, define those criteria which will affect the welding operations. These criteria include the

- Water depth at which the repair is to be made.
- Exact radiation levels of the repair pieces, at contact, and at six inch intervals to 2' feet from point of contact.
- Type, thickness, and grade of metal(s) to be welded.
- Range of access clearances available at the work site.

Obtain these first two items from the preliminary visual inspection. The latter items should be readily available from plant engineering drawings of the system.

In assessing the results of these inquiries, determine whether to plug or replace any damaged nozzles. After selecting a repair option, fabricate a mock-up of the weld joint detail and damage site to demonstrate the physical accessibility of the work to the diver. Use the mock-up to qualify any required welding procedure and diver-welders selected to complete the work. Using this training mock-up, divers should attempt a minimum of the following operations in developing a proposed welding procedure:

- Removal of existing damaged nozzles and piping.
- Surface preparation required for sparger pipe exterior.
- Removal of knuckle clamp from sparger pipe interior.
- Shaping and preparation of resultant sparger pipe hole.
- Shaping and fitting of sparger pipe plug.
- Tack, cleaning, and welding of plug to sparger pipe.

The welding procedure describes the following information:

- Method for accomplishing the repair.
- Type of welds to be used.
- Position of welds as laid down.

- Joint details for each individual weld.

An example of the joint detail selected for use m the earlier plugging repair was a 60 ^{o} included angle butt joint with a 1/32" to 1/16" root opening and 3/32" root face. This produced a weld with 80-85% penetration. Penetration representing the depth to which the weld metal laid down fuses to, or penetrates, the base metal. 100% penetration would represent the full thickness of the base metal piece.

After defining a proposed welding procedure, the procedure must be qualified according to a welding code, before being approved for use. In addition to qualifying the procedure, it is also necessary to qualify individual welders' to perform the work. Each of these can be done at the same time. Use the training mock-up, and the two welding codes which cover this type of repair, to perform these qualifications. These welding codes are:

- ANSI/AWS D3.6-89, Specification for Underwater Welding.

- ASME Boiler and Pressure Vessel Code, Section IX-Welding and Brazing Qualifications.

The AWS D3.6 specification deals primary with underwater wet welding, while the ASME section IX code applies to general topside welding specifications for this type of work. Use ASME Section IX to govern all facets of the welding, except those variables such as depth which are peculiar to underwater welding. Use AWS D3.6 for these aspects of the procedure.

After completion and approval of the welding qualifications, and demonstration of the feasibility of the repair scenario, begin to consider means of achieving ALARA goals during the repair. Use stainless steel, or stainless steel clad plate, for radiation shielding in all areas m which the shielding plate might contact stainless steel. Other steels may induce corrosion m stainless if they are allowed to scratch it's surface during use. Following are several actions which are effective in this regard:

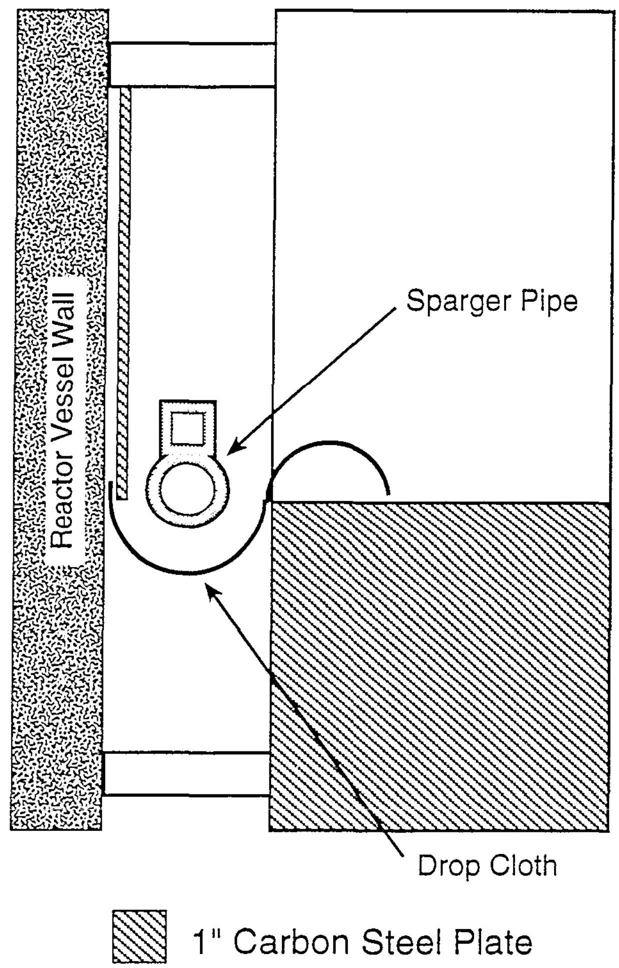
- Fabrication and use a divers work stage, hung from the reactor head flange stud bolts, fitted with waist-high shielding plate on the three radiation-exposed sides and bottom, allowing the diver to enter from the rear and safely approach the sparger pipe and nozzles. Standoffs located top and bottom on the stage also serve to provide a fixed distance from both the reactor vessel wall and sparger pipe. This also provides the diver with a constant visual reference.

- Hang a shielding plate directly in front of the divers' work station, behind the sparger pipe, against the reactor vessel wall. This serves to both shield the diver from excess radiation exposure, and prevents any chance of accidentally striking a welding arc against the reactor vessel wall.

- Hang of a piece of lead-impregnated material from the bottom of the shielding wall plate, dropping down behind the sparger pipe, retrieved underneath the sparger pipe, and fitted in over the top of the front of the divers' work stage. This serves not only as a loose parts drop cloth, simplifying final cleanup procedures, but also provides additional shielding for the working divers.

- Hydrolasing of the both the reactor vessel wall and sparger pipe assembly m the area of the repair site. In the above referenced repair, radiation values diminished from 5-3 r/h on contact, and from 1.5 r/h to 325 mr/h at 12 inches, as a result of hydrolasing.

The following diagram in Figure 4-2 depicts the described divers work platform and its relationship to the work area.



DIVERS WORK PLATFORM DIAGRAM
Figure 4-2

These actions allow the full use of available bottom time, on the no-decompression diving table [reference Appendix III], for each dive at that depth.

4.8.2. Equipment

The equipment required for this type of repair operation falls into four major categories:

- Underwater Cleaning
- Underwater Metal Cutting
- Underwater Welding
- Fiber Optic Inspection

In underwater cleaning, both an underwater vacuuming system and hydrolasing equipment are required. The underwater vacuum system is helpful in removing any dross, slag, or other material which might develop as a result of the repair operations. Use it to remove debris from the general work area, as well as from within the sparger pipe itself, after removing the nozzle. Use the hydrolaser to decontaminate repair surfaces before beginning repair operations. A thorough discussion of this equipment is found in Chapter 3 of this guide.

Perform the underwater metal cutting required for this repair, such as in removing damaged nozzles, by using either an electric arc-water gouge or tungsten-carbide burring tool. This equipment and its usage is more fully discussed in Chapter 3 of this guide.

There is no requirement for any unusual underwater welding equipment for this type of repair. A thorough discussion of this equipment is found in Chapter 3 of this guide.

Use a fiber optic inspection system for the interior examination of the sparger pipe, before beginning the plugging phase of the repair. These inspection systems vary according to their manufacturer, but generally consist of a manually-flexible fiber optic stalk, 6"-18" in length, attached to a video camera.

4.8.3. Guidelines

Begin operations with a visual inspection of the known damaged areas to determine the scope and cause of the existing damage. After evaluation of this information, reinspect the general surrounding area of interest, as well as any additional areas indicated by the damage evaluation.

After completing a final determination of the total extent of the damage, develop a scope of work which reflects both the exact nature of the existing damage, as well as any special considerations pertaining to the potential repair. Prepare any drawings of the damage areas to illustrate the position and extent of damage. If possible, collect both video and still photographs of the area for later review.

Develop a repair scenario based on the qualification of both the welding procedures and welders, and test in actual operations performed on the underwater mock-up of the repair site. Do this to the extent necessary to validate the process.

Secure any special materials and equipment necessary to meet ALARA goals, such as the divers' work platform and shielding materials, and deliver to the work site. Determine the distance from the mid-line of the sparger pipe to the reactor flange stud bolts. This information will be required to fabricate the cabling supports required for proper location of both the protective reactor wall plate and divers work platform, previously described.

Install all diving and related equipment necessary to affect the repair at the work dive station, in accordance with guidelines outlined elsewhere in this guide. Install all equipment in conformance with existing plant guidelines for such items.

Lower the 1" carbon steel protective plate and drop cloth assembly to just above the approximate depth of the work site. With a diver or ROV supervising, move it laterally towards the reactor vessel wall. When the plate/drop cloth has reached a point in the vertical plane between the inside diameter of the sparger pipe and the reactor wall, lower the assembly until the bottom of the plate is even with the bottom outside diameter of the sparger pipe. This places it between the sparger pipe and the reactor wall. Hang the cabling holding the plate onto the reactor flange stud bolts. This acts to secure the plate at a fixed depth and position.

Lower the divers' work platform to the work site depth, and in like fashion, move it laterally towards the reactor vessel wall until the standoffs are against the wall. Suspend it also on the reactor flange stud bolts using cables.

After placing these two pieces of equipment, begin decontaminating the work area using a waterblaster. Clean the sparger pipe and nozzles, as well as portions of the immediate reactor wall not otherwise shielded by the plate/cloth assembly.

After finishing with the waterblaster, remove the equipment to the surface. A diver, using extension tongs if necessary, should then reach and grasp the bottom of the drop cloth shield hanging below the sparger pipe, and bring it up under the pipe, and fit the end into the front of the divers' work platform. This not only completes the radiation barrier, but provides an effective means of controlling the collection of loose materials and debris at the repair site.

Complete a radiation survey of the repair site to determine the level of improvement to ALARA goals. Begin repair operations after receiving approval from plant HP personnel in charge.

The diver will begin by attaching a ground connection to the sparger pipe, and deploying the arc-water gouge to the work site. He will then begin using the arc-water gouge to remove the damaged areas from the pipe.

Use a water-driven hand grinder to clean and dress the remaining hole, in preparation to receive a plug.

Again using the arc-water gouge, remove the interior knuckle clamps in pieces. In actual operations, reattach the ground connection clamp directly to the knuckle clamp each time a piece is cut. This prevents the accidental arcing of the gouge onto the sparger pipe. Secure the arc-water gouge after completing this operation, and return it to the surface. Reconnect the ground clamp to the sparger pipe in preparation for welding.

Use a water-powered grinder to prepare both the weld joint and weld bevel for welding, according to the welding procedure specified.
Deploy an underwater vacuuming system, with a flexible nozzle attached to the suction hose. It should be of such diameter to allow the introduction and manipulation of the nozzle through the repair hole in the sparger pipe. Using this method, remove all loose parts, dross, and other metal cuttings from interior of the sparger pipe. Vacuum the drop cloth underneath, as well.

Deploy the fiber optic inspection probe to the repair site. Insert it into the sparger pipe to confirm the absence of remaining debris and that no undetected damage exists to the interior of the sparger pipe or adjoining nozzles.

Slip an appropriately sized piece of stainless steel shim stock through the existing repair hole and hold in place. Fabricate it so that it provides a surface upon which to scribe the internal diameter of the repair hole. Paint the scribe-side of this shim with layout blue. Scribe the approximate dimensions of the hole on that side of the shim. Return the shim to the surface where a suitable plug can be fabricated from the measurements taken from the scribed piece.

Fabricate an "X"-shaped bar piece and tack to the top surface of the pre-cut plug. Extend the ends of each bar past the circumference of the plug, enabling them to rest on the surface of the sparger pipe and thus automatically align the plug in the hole. While the brace placed in line axially with the top center of the sparger pipe will not require any adjustment, angle the bracing at right angles to the axis of the pipe in such a manner to compensate for the curvature of the pipe. This will enable the plug to be easily and accurately held in the proper position for subsequent tacking by the welder before the actual welding begins. After tacking, remove the brace to allow the welder unrestricted access to the weld area.

The plug is now ready to weld in accordance with the exact welding procedure determined for the particular repair. Deploy the welding lead, pneumatic chipping gun, and supply of welding rods to the work site. Lay down the each weld pass in accordance with the predetermined weld specifications. Use the pneumatic chipper, as necessary, for interpass cleaning of the weld. Upon completion of the final weld pass, perform a visual inspection of the entire weld to determine if any obvious flaws or questionable areas exist. Record this inspection on video for review and concurrence by plant welding specialists.

After all necessary plant and contractor personnel agree that the welding operations are both successful and complete, secure the welding lead, chipper, and remaining rods and remove them to the surface.

Use the underwater vacuuming system to clean up the resultant slag, consumed rod pieces, and other debris in the area. Once completed, remove the vacuum bag from the unit and disposed of, according to directions from HP personnel. Remove the vacuuming system from the pool.

Attach any remaining tools to the interior of the divers' work platform. Release the drop cloth and bring the platform to the surface, in a manner similar to its deployment. Retrieve the protective plate and drop cloth after the work platform is safely on the surface.

Conduct a final visual inspection of the repair site and general area to be sure that no accidental damage was done to the sparger pipe, adjacent nozzles, or the reactor vessel wall during repair operations. Check that the area is free of all loose parts before leaving the site.

4.9. Welded Repair of Steam Dryer

4.9.1 Introduction

Stress cracking is a problem of BWR steam dryers. This often occurs along weld joints located between the hood and end panel of the dryer. The failures have occurred in weld metal along the fusion zone on the side of the joint. Repairs have consisted of both the welded repair of the existing cracks, as well as installation of reinforcement plates to as yet unaffected members, as a preventive measure. Several plants have experienced this problem, with welded repairs performed both in the dry, and by wet welding underwater. The latter method has been determined to have the least impact on other scheduled outage activities, as well as serving to maintain plant ALARA goals for radiation exposures.

In performing the welded repair of these stress cracks, due to the internal configuration of the steam dryer design, no backside access exists from which to install a backing plate for the repair weld. In some instances, the stress cracks have opened a sufficient distance to allow the installation of backing plates from the front. however, their use may not be desirable due to concerns of subsequent corrosion and increased vibration problems.

As with any welded repair, the specific welding procedure to which weld must be qualified and performed must be determined. Since the steam dryer does not act as a pressure vessel, nor serve in a safety-related function, it is not necessary to qualify the weld to ASME Section IX welding specifications for such items. The AWS D3.6 underwater wet welding specification for Type B welds is capable of covering all conditions necessary for the successful performance of the welding repair. Type B welds represent the highest standards intended to be applied to underwater wet welds. The following weld tests represent the best repair results for this application:

- to 1/8" and 1/4" to 1/4",< 60^{o} single V-groove butt joint welds requiring a minimum 65% penetration, performed in the 3G (vertical down) position. The optimum configuration to achieve maximum penetration was found to occur with the root face tightly butted.

- Fillet welds tested included 1/8" to 1/8" and 3/16" to 3/16" T-joints and 1/8" to 3/16" lap joints, performed in the 2F (horizontal) and 3F (vertical down) positions.

The resultant welding procedure has been qualified for wet welding 75% partial penetration 3G groove welds on 3/32" to 3/8" thick Type 304/304L base metal, and for 2F and 3F fillet welds on 3/32" to 3/4" base metal, in depths ranging from 6'-43' ffw, using low carbon (< 8.0 minimum ferrite number) stainless steel electrodes with mild steel core wire. These electrodes were also compared with those containing stainless steel core wire, and found to offer superior performance in this application, particularly on the thinner metals.

The following represents a general sequence of events for this type of repair:

- Determination and qualification of the welding procedure and welders to be employed for the repair.
- Installation of the required contractor equipment at the plant, and configuration and testing of the dive station.
- Removal of the steam dryer assembly from the reactor and placement in the equipment pool.
- Decontamination of the steam dryer areas involved and general vacuuming of the area.
- Installation of the divers' work platform at the repair site.
- Diver inspection of the cracking area and performance of fit-up required to support welding requirements.
- Wet welding repair of the crack.
- Underwater video inspection of the welded repair and certification
- Removal of underwater equipment from the pool and general cleanup and vacuuming of the pool area.

4.9.2. Equipment

The following equipment packages are required to complete this type of repair:

- Diving equipment
- Underwater wet welding equipment
- Underwater vacuuming equipment
- Pry bar/mechanical jack
- Divers work platform
- Underwater video camera and recorder

The diving equipment, underwater welding equipment, and underwater vacuuming equipment, required to support this repair operation are each discussed in detail in their respective sections of Chapters 1 and 3 of this guide.

Pry bars are required to manipulate the dryer joint crack back into position for grinding of the V-groove and tacking. A long bar of about 5', and a short bar of about 2.5' should be sufficient, each possessing a chisel point end. One or more mechanical jacks may also be required to leverage the steam dryer joint into an approximate position for fit-up of the weld joint.

The underwater work platform required by the divers for this special type of repair is custom made to fit the exact curvature of the steam dryer itself, providing maximum access for the diver welder. It may be equipped with sliding metal doors covering the access to the dryer, to provide the diver with the ability to close the doors during periods of inactivity. This reduces the total potential radiation exposure.

The underwater video camera system, as discussed elsewhere in this guide, should consist of a handheld B & W low-light level camera, equipped with variable intensity lighting. This arrangement will provide the best fine image resolution for accurately inspecting and documenting the welded repair. The recorder should be equipped with a 'pause' control to allow the operator to edit the inspection, to conserve runtime and provide greater continuity in review.

4.9.3. Procedures

Begin by vacuuming the pool area in the vicinity of the work site to decontaminate the area in preparation for the work to begin. Do this by first cleaning a base area from the surface from which the diver can work to complete the cleaning.

Install the divers' work platform as closely as possible to the face of the steam dryer, allowing enough room between for the positioning of the vacuum suction. This will provide automatic collection of dross and slag produced during repair operations.

Begin the repair process with an initial inspection of the repair site, to confirm the extent of the cracking and suitability of planned procedures for the repair. Make any adjustments for equipment repositioning, or procedural changes identified, at this point.

Deploy the underwater vacuuming system, with the suction hose end fitted with a wide-mouth inlet. Securely position the inlet below the repair site, in such a manner as to collect dross and slag produced during repair operations. Do not position the inlet or hose so closely that the water flow induced in the area impairs the divers' ability to perform the welding tasks.

After completion of the initial inspection, begin the fit-up process necessary to start the actual welding operations. This process consists of physically manipulating the cracked sections of the dryer back into their original positions, as necessary. Do this using manual pry bars and jacks.

After closing the crack, use a 90^{o} water-powered grinder and abrasive wheel to prepare the crack for welding. This is done by grinding out the rough edges of the crack, and dressing the crack into a V-groove. Refit the dryer until the bottom of the V-groove root faces of the crack are as close to a flush fit as possible.

Deploy the underwater welding equipment to the work site, and perform the following test functions:

- Weld test beads on an underwater plate at the depth of the repair site, to determine the best setting adjustment of the welding power supply for the existing conditions and speed of application.

- Perform a confirmation weld, of a length considered representative of the quality of the welding being performed. Have each diver perform this confirmation weld before beginning each weld. Bring each confirmation weld to the surface for visual inspection and acceptance before welding on the dryer assembly.

Begin the actual welding on the dryer by laying down a tacking bead about 4' in length along the bottom of the crack. Readjust the fit-up to continue to close the crack as more tacks are placed further along the crack. Repeat this process until the crack has been completely tacked in place, in a position suitable for welding.

Once the tacking process has secured the proper position of the V-groove over the entire length of the proposed weld, lay down the remainder of the root pass between the tacks, in accordance with the welding procedure defined.
Clean the completed root pass weld of any slag using a pneumatic needle gun, or chipper. Visually inspect the root pass to be sure that no irregularities in the weld exist. If found, grind them out using a pneumatic pencil grinder fitted with a carbide burr, and rewelded to meet specifications.

Once a successful root pass is completed, lay down the filler passes required on top of the root pass. The filler passes should fill the remaining V-groove of the weld. Clean away slag using a needle gun or chipper, before applying each filler pas. Perform a final visual inspection after completing the welding.

Perform this final inspection using a handheld video camera linked to a video cassette recorder and monitor on the surface. Inspect the entire weld and recorded for future review. After the inspection diver and the plant welding engineer have completed their inspection and approved the weld, recover all welding and video equipment to the surface. Rinse each piece with demineralized water, and wipe dry, as it comes out of the pool.

Vacuum the general work area, including the steam dryer itself. Also vacuum the divers' work platform and the floor of the equipment pool. Once completed to the satisfaction of HP personnel, remove the vacuum, then the divers' work platform, to the surface.

Where preventive maintenance, in the form of the welded installation of weld seam reinforcement plates, is to be conducted, follow these minimum guidelines:

- Use and aluminum plate, of the size to be used for the reinforcement of the weld, to scribe a template of the joint to be reinforced. Use two divers, one to hold the plate and the other to scribe the joint detail upon it.

- Recover the template to the surface, where the reinforcement plate can be fabricated from the scribed template piece.

- After fabricating the reinforcement plate, use two divers to maneuver and tack the plate into position on the steam dryer joint.

- Use one diver at a time to weldout the remainder of the reinforcement plate to the steam dryer joint. Continue in the normal manner until the plate has been completely attached.

- Where multiple reinforcement plates are to be attached to each joint of the steam dryer as preventive maintenance, fabricate and tack each of the templates into place, before beginning the final weldout of each piece. This allows the steam dryer to be rotated as necessary, providing the divers access to each repair site, without moving the work platform and welding equipment on the floor of the pool.

- As with any pool operation involving underwater welding and cutting, finish operations with a thorough examination of the area and vacuuming of the work site.

4.10 Water Storage Tank Inspection

4.10.1 Introduction

Each nuclear power generating station collects and stores several large volumes of water to meet a variety of site operational requirements. Each vessel or its coatings may require periodic inspection, either to meet existing regulatory requirements or to satisfy a specific maintenance issue. The following list of major water storage tanks found at nuclear powerplants may require periodic inspection using underwater services:

- torus or suppression pool
- condensate storage tank
- Rad-waste tanks
- demineralized water tank
- fire protection reservoir
- sanitary services reservoir
- standby cooling water reservoir

General inspection guidelines can be found within ASME section XI, "Rules for Inservice Inspection of Nuclear Powerplant Components" of the American Society of Mechanical Engineers Boiler and Pressure Vessel Code. In addition, tankage may also have specific inspection requirements delineated by section D101-53, "AWWA Standard for Inspecting and Repairing Steel Water Tanks, Standpipes, Reservoirs, and Elevated Storage Tanks for Water Storage", of the American Water Works Association, or API RE-13, "Guide for Inspection of Refinery Equipment" (1981), "Atmospheric and Low Pressure Storage Tanks" (Chapter 13).

There are two principal types of underwater inspection used for storage tanks. They are 1) visual inspection and 2) non-destructive examination (NDE). Depending upon the specific scope of work, one or both methods may be employed, in order to acquire the necessary inspection information for a given system.

Visually inspecting the internal walls, piping, and components of the storage tank is most often performed to:

- ensure that both system supply and discharge orifices are free from obstruction, and in proper working order.
- determine the amount of sludge or sediment accumulated in the tank.
- identify areas of coating damage, in coated tanks.
- locate debris, loose parts, or other foreign objects which may have accumulated in the tank.

Visual inspections can be performed with divers usinghand-held video; with camera-equipped remotely-operated vehicles (ROV); with drop cameras; or through using camera-mounted extension tubes. In some instances, visual inspection of subsurface areas may be performed directly by surface personnel, where only a general observation is required and water clarity permits.

NDE implies the methodical utilization of an inspection system to provide a relative physical evaluation without permanently altering the test material, in this case the tank or its internal components. The most common forms of underwater NDE used in storage tank inspections are ultrasonic testing (UT), pit gauge measurement, and vacuum box leak detection whose performance is covered in detail in section 4.5, "Pool Liner Repair".

In storage tank inspections, NDE is most often performed to:

- gauge the wall thickness of metals used in the structure and piping of tanks, as a general indication of the level of corrosion present in the system.
- determine the size and depth of pitting apparent on tank and piping components, as another indication of surface corrosion.
- locate minute leaks in the tank structure or piping.

Underwater NDE can be performed using divers, or through telerobotic means. In some instances, it can also be performed effectively using an ROV.

4.10.2 Equipment

Use only standard, surface-supplied diving equipment for inspection operations within enclosed tanks and other confined spaces. Due to the lack of an auxiliary air supply and voice communications, standard SCUBA equipment is generally inappropriate for use in such operations. The most important considerations when planning enclosed tank inspections using divers, are to:

1) provide a readily-available secondary breathing gas supply in case of emergency.

2) maintain a reliable communications link between the diver and surface support personnel.

A detailed discussion of surface-supplied diving equipment is provided in section 1. 3, '"Diving Equipment", of this guide.

Depending upon whether the subject tank contents are radioactively contaminated, full dry-suit diving dress may or may not be required by the diver performing the inspection operations. Full dry-suit diving dress may also be desirable when entering non-radioactively contaminated storage tanks, as when entering the demineralized water tank, to preserve the purity of the tank contents.

If diving operations are to be conducted in tankage where the water temperature is above 95^{o}F, it may be necessary for the contractor to provide chilled-water vests for use by the divers. Check with the underwater services contractor regarding their individual policies for use of such equipment.

If the surface of the water in the tank is more than a few feet from the access way, use a "bell harness" to facilitate the safe and efficient recovery of a potentially unconscious diver. This type of harness possesses an integral D-ring positioned directly over the top center of the harness back, near the nape of the neck. In the event that such an emergency recovery is necessary, a surface lifting line can be easily attached to this D -ring, providing a direct line of pull to recover the diver most easily.

In selecting an ROV to perform a storage tank inspection, physical size is the primary consideration. The vehicle must be capable of passing through the access way into the tank, in order to perform the inspection tasks. Smaller ROV's have a distinct advantage for most tank inspections, in that they are easily deployed and recovered manually, by a single individual. Smaller ROV's are also generally more maneuverable once inside the tank, and thus are able to more easily avoid internal tank piping and other physical obstructions.

The selected size and operating speed of the thrusters which propel the ROV are a function of the vehicle's size and mass. Small vehicles can make use of smaller thrusters, operating at fewer revolutions-per-minute. When used inside an enclosed tank, this translates into less turbulence in the water, which significantly improves the relative visibility for the camera system.

A detailed discussion of ROV equipment is provided in section 2.3 of this guide.

When performing storage tank inspections, there may be a requirement for a number of special tools necessary to facilitate various aspects of the inspection. Depending upon whether the inspection is performed using a diver or an ROV, and the physical location of the tank access way, these tools may include:

- a wrench
- a ladder
- a lift line, or block & tackle
- auxiliary lighting array
- a temporary access way shelter

If the tank to be inspected is not normally open to the atmosphere, it will be necessary to determine what tools are necessary to gain entry. In general, normally closed access ways are secured with a some type of hand wrench. Prior to beginning operations, size and locate the appropriate wrench for the access way in question. As with all hand tools, attach a lanyard to the tool handle to prevent accidentally dropping the tool into the open tank.

A ladder may be necessary to assist a diver in entrance and egress from the tank, particularly if the surface of the water is more than a few feet from the access way. Select a ladder which can be securely attached to the access way opening, of sufficient length to extend several feet below the water's surface. In tanks providing poor visibility, attachment of a suitable underwater light to the lower end of the ladder may improve the diver's ability to quickly locate the ladder in the event of an emergency. Instruct the diver to turn on the light upon entering the tank, and turn off the light upon returning to the ladder to leave the tank.

A lift line, or block & tackle assembly, may ease the deployment and recovery of an ROV through the access way. It can also be positioned directly over the access way, in the event that an unconscious diver must be manually recovered in an emergency. If the assembly is being used to deploy/recover an ROV, attach a standard open hook to the end of the lift line. This will allow the hook to slide out from its attachment point, as the ROV is lowered to a floating position at the surface of the water. If the assembly is to be used as a rescue device, attach a lifting hook to the end of the lift line possessing a positive-closing, spring-loaded mouse assembly. This will prevent the unconscious diver's harness D-ring from accidentally slipping off the hook during an emergency recovery. In either case, use a hook of proper size which can easily be attached/removed from the intended attachment point.

Depending upon the type of tank and inspection to be performed, an auxiliary lighting array may be necessary to provide sufficient light to perform the inspection. Auxiliary lighting can range from a small, battery-operated light handheld by a diver or attached to an ROV, to a corded light or lights, powered and suspended from the surface. Attach a lanyard to all handheld lights to prevent their accidental loss in the tank. Securely a battery-operated light to an ROV in a location where it is less likely to be dislodged in the event of a collision with an obstruction in the tank, during operations. Protect surface-powered corded lights with a wire bulb guard to prevent their accidental damage while in use.

The safety and efficiency of inspection operations may benefit if tank access ways, depending upon certain conditions, are protected by constructing temporary shelters around the opening. The two main reasons for such shelters are to 1) protect the surface support personnel from the weather at outdoor locations, and 2) to limit the potential spread of contamination in radiologically-controlled tank areas, such as the condensate storage tank.

Handheld video equipment used for recording underwater visual inspection is available from a number of manufacturers servicing the commercial diving market. Each system consists of the following four (4) major components:

- a video camera fitted in an underwater housing.
- an electrical umbilical
- a video cassette recorder (VCR)
- a display monitor

Underwater video cameras are currently available in a range of sizes and configurations. Cameras are available that provide a range of output quality, from simple black & white to broadcast quality color images. Cameras are also available with fixed- or auto-iris, and fixed- or remote-focus lenses. Handheld underwater cameras are generally fitted with a pistol-grip style mount to facilitate ease of handling by the diver. Lighting is normally attached to the exterior of the camera housing. Both black & white and color cameras are capable of providing excellent image resolution, which in practice, is somewhat better than that of the diver directing the camera. Color cameras offer no real advantage in most underwater visual inspections, with the exception of corrosion inspections, where color output is useful in assessing various levels of corrosion. Remote focus is useful in allowing surface personnel to directly control camera focus, bypassing otherwise necessary instructions to the diver for manual camera guidance. The auto iris feature is generally useful reducing the amount of manual adjustments necessary to maintain acceptable picture quality. However, remote or manual iris adjustment is sometimes desirable to increase the apparent resolution of detail in the inspection area,

A waterproof umbilical containing the necessary electrical conductors, connects the underwater video camera to the surface VCR. The umbilical may or may not be neutrally buoyant. Attach a short tether from the camera housing to a point near the camera end of the umbilical. Do this in such a fashion as to provide a relief mechanism for any strain which might otherwise be imparted to the umbilical attachment plug at the camera during operations and handling.

Connect a standard VCR to the underwater video camera, using the umbilical. Use a VCR which provides a 'pause' feature, as well as a video footage counter. Use these features to conserve tape and reference the inspection video log. Some commercial VCR systems include an analog character generator which allows the operator to include typed comments with the video signal. These appear as text overlays on the viewing monitor during the appropriate segments of the video sequence.

Select a video monitor to view the underwater camera signal which possesses both brightness and contrast controls. These controls allow the viewer to manually adjust brightness and contrast to their optimal levels for improved visual clarity over a range of images.

The equipment necessary for the performance of NDE varies according to the type of testing performed. Consult with the contractor selected to perform these services to determine the type of equipment required.

4.10.3 Procedures

Prior to performing any type of storage tank inspection, determine whether the subject tank requires compliance with operating procedures for confined spaces. In general, a confined space is one which shares some or all of the following characteristics:

- Sufficient size to accommodate personnel entry
- Limited or difficult personnel entrance or egress.
- Not intended for continuous occupancy.
- Hazardous or unbreathable atmosphere.
- Contains a material capable of engulfing an occupant.
- Interior configuration capable of trapping an occupant.

A confined space can be defined as any space so enclosed that it is not intended for normal occupancy and has a limited means of entry and egress, and is subject to:

- the accumulation of unacceptable levels of toxic gases or vapors, as specified in 29 CFR 1910.1000 Subpart Z.

—or—

- an accumulation of combustible gases or vapors in concentrations at 10% or higher of the lower explosive limit (LEL).

—or—

- unacceptable levels of oxygen, in concentrations less than 19.5% or greater than 21.4%.

Initially, determine whether the subject tank meets the necessary qualifications for designation as a confined space. If so, check with the appropriate department responsible for maintaining an in-plant confined space operations procedure for guidance. In the absence of a developed procedure, consider the following guidelines when planning the storage tank inspection.

Before commencement of operations in a confined space, give proper consideration to the level of personnel training which you may wish to require. At a minimum, ensure that each person directly involved with the performance of the inspection operations holds a current American Red Cross (ARC) cardiopulmonary resuscitation (CPR) certification, and that at least two (2) persons also hold current ARC First Aid certifications. If the Utility has a Confined Space Training Course in place, consider whom should attend prior to operations. Brief all personnel who will enter the tank on the following:

- general entry and egress procedures
- potential hazards and obstructions
- emergency egress procedures and responsibilities

When the subject tank to be inspected represents a normally-closed system, begin by determining whether any significant pressure differential exists across the intended point of entry. In the event that such a differential does exist, plan to equalize the tank internal and external pressures, prior to opening the access way. Likewise, determine which piping supplies the tank, and plan to tag-out those lines during the inspection period. If open piping to other voids exists within the tank, evaluate whether to isolate those voids from the subject tank, or take similar precautions for those voids as well.

Immediately upon opening the access way to a confined space, use appropriate monitoring equipment to test the specific atmosphere within the tank. Select atmospheric monitors which will provide an accurate indication of oxygen and combustible gas levels within the tank. Ensure that each test instrument is properly and currently calibrated. Oxygen sensors should read approximately 21% oxygen in a fresh air atmosphere. Methane may be used to calibrate most sensors of combustible gases. Ensure that all test equipment is used in accordance with manufacturers recommended tolerances and procedures for such equipment and operations.

Perform this testing from outside the access way, prior to entry by any person into the tank. Continue preliminary testing for at least five (5) minutes duration. This includes monitoring of the entire space. If this is not possible while remaining outside the access way, then an individual using a handheld test probe must enter the tank to complete the survey. Equip that individual with a full body harness, attached to a safety line. Attach one end of the safety line to a D-ring on the harness, and the other end securely to an external lifting device, or bit, capable of supporting two (2x) times the weight of the individual. If while performing the internal atmosphere survey, any negative readings are recorded, the individual performing the survey will immediately exit the tank.

If the survey determines that the internal atmosphere is outside established parameters for a breathable atmosphere, prepare to ventilate the space until the atmospheric volume has been exchanged a minimum of seven (7) times, according to the following formula:

$$\frac{\text{Atmospheric Volume (Ft}^3\text{)}}{\text{Blower Rating (CFM)}} \times 7 = \text{Minimum Purge Time}$$

The atmospheric volume (Vatm) in a rectangular tank is calculated as follows:

[T1 x Tw x (Th - Lh)] = Vatm

The atmospheric volume (Vatm) in a circular tank is calculated as follows:

(3.1415 x Td) x (Th - Lh) = Vatm

Where:
- Tl = Tank length
- Tw = Tank width
- Th = Tank height
- Lh = Liquid height
- Td = Tank diameter

CAUTION

Where a combustible atmosphere exists, purge those gases from the tank using an inert gas, prior to ventilating the tank with air.

Monitor the atmosphere at regular intervals, as appropriate, and record the findings in the job log. Resume forced ventilation as necessary to maintain a breathable atmosphere within the tank while operations are underway.

If forced ventilation is successful in alleviating unbreathable atmospheres which exist for reasons other than unsafe oxygen levels or the presence of combustible gases, such as with toxic atmospheres, continue forced ventilation for the duration of inspection operations, or as long as conditions causing the toxic atmosphere exist.

CAUTION

Consider whether the performance of any proposed work tasks, such as welding, chemical cleaning, or coating applications, might adversely alter the tank atmosphere over the course of the operations.

NOTE

In the event that an emergency rescue of a tank occupant is required, notify the appropriate Utility emergency response office immediately. Where the occupant has fallen unconscious, or the tank atmosphere is questionable, do NOT enter the tank without donning an appropriate emergency breathing apparatus.

In storage tank areas, radiologically-controlled areas (RCAs) include the condensate storage tank (CST), torus or suppression pool, and Rad-waste tanks. When planning entry into a storage tank which is also an RCA, ask Health Physics (HP) personnel to determine the level of radiation present in the tank water through sampling and issue a report in advance of the intended operations.

Prior to opening the access way to the tank, make the following provisions for controlling the potential spread of radioactive contamination from the tank, during operations.

- Construct an appropriate containment barrier of sheet polyvinyl chloride (PVC) surrounding the access way, to limit the spread of airborne contamination. Divide the area within the containment into 'clean' and 'contaminated' areas, with the access way being in the contaminated area.

- Cover the containment flooring with PVC, and fold the edges of the sheeting surrounding the access way into the opening, in such a manner that water dripping from items removed from the tank will drain back into the tank.

- Route a demineralized water supply hose to the area of the access way, having sufficient volume and pressure to be effective in rinsing items for the purpose of decontamination before they are removed from the tank.

- Post the appropriate signage in the area, notifying interested parties of the open access way and RCA.

Immediately upon opening of the access way, request that HP personnel perform the following tests, prior to tank entry or commencing operations:

- A high-volume particulate matter test, for at least five (5) minutes duration, to gain an early estimate of particulate matter levels in the tank atmosphere.

- Collection of a water sample for analysis.

- A tank radiation survey, beginning with a drop probe to the surface at the point where the diver or ROV will enter the water.

After receiving the approval of HP personnel to continue, perform a radiation survey of the tank to establish a baseline for comparison. Prepare a radiation survey map from this data to assist in planning subsequent inspection operations.

NOTE

For diving operations in RCA's, follow those guidelines located in section 1.5, "Contaminated Water Diving", and elsewhere in this guide.

Establish a low-volume particulate matter sampler for airborne particles to run continuously during operations. Monitor the equipment and remove the sampling filters twice per day for examination by HP personnel.

To ensure the safe and efficient performance of storage tank inspections, an important part of the pre-job planning should include the evaluation of related structural drawings, and the impact of operations on tank contents and vice-versa.

With regard to the evaluation of the structural features of each tank, obtain copies of those drawings which detail the internal features of the tank. In studying these drawings, the following areas need to be identified:

- tank inlet piping and inlet openings
- tank discharge piping and suction openings
- structural members and internal bracing
- other structural features which deviate from a smooth interior tank surface
- type and specification of existing interior coatings

Where flow rates associated with tank inlet piping might be sufficient to be of concern, with respect to the safety of the diver or ROV operating within the tank, lock-out and tag control valves associated with this piping. In certain situations where the piping is part of an automatically-actuated stand by safety system and cannot be taken out of service, fabricate metal flow deflectors for each pipe opening which can be installed and positively locked in position across the face of the opening to deflect any direct flow laterally towards the side of the tank, away from the diver or ROV work area.

Where flow rates associated with tank discharge piping might be sufficient to be of concern with respect to the safety of the diver or ROV operating within the tank, lock-out and tag control valves associated with this piping.

CAUTION

When performing operations in tanks with gravity-flow drain lines, remember that the head pressure of the water column in the tank may be sufficient to cause severe injury to a diver or disrupt ROV operations if either inadvertently comes in contact with a flowing drain opening during operations.

In certain situations where the piping is part of an automatically-actuated standby safety system, such as the High Pressure Coolant Injection (HPCI) system, and cannot be taken out of service, fabricate metal grille protective enclosures for each piping opening which can be installed and positively locked in position around the opening. Use maximum flow estimates for each pipe opening in calculating the size and dimension for fabricating each enclosure. The completed enclosure must standoff from the pipe opening a sufficient distance in all directions to provide a safe barrier for the diver or ROV, in the event of an automatic discharge from the tank. Higher flow openings may require grille barriers larger than the tank manway opening. In this situation, fabricate a two-piece barrier which can be easily and positively joined together after both sections are inserted through the tank manway.

Study the size, configuration, and placement of all tank internal structures and bracing to develop a planned inspection pathway which promotes efficient and safe operations by either divers or ROV's. Pay special attention to the umbilical position which may change during operations, as the diver or ROV moves about the tank. In both cases, and particularly with respect to the diver, it is extremely important that the planned inspection pathway maintain a umbilical position such that, in the event of an emergency involving an unconscious diver or disabled ROV, surface personnel can manually extract the diver or ROV easily and directly from the tank by using the respective umbilical as a lift line. In the case of diving operations, consider whether the configuration of tank internal structures, or the divers' work path, relative to his point-of-entry, warrant the positioning of a second diver at some point inside the tank for the purpose of tending the primary diver's umbilical.

Note any points along the tank floor or walls, or on interior structures, where the umbilical might become entangled or damaged, if fairleaded across the point during operations. Consider how those areas might be avoided by the diver/ROV and umbilical, or what safeguards might be utilized to minimize any risk of entanglement.

Finally, determine the type and durability of any coating systems installed on the inner tank walls or interior structures. Determine whether what steps might be necessary to preserve their integrity, such as positively tethering tools used within the tank to prevent their being dropped, or the installation of soft bumpers around an ROV.

From an overall structural perspective, note both the number and position of manways available for tank entry, and their size and configuration. This information may have an impact on both the later placement of required surface support equipment and the planned inspection pathways used by the diver or ROV operator, as well as the size of the equipment which can be scheduled for use in the tank. Also note the distance from the manway used as the tank point-of-entry to the water's surface. For diving operations, in most cases this distance will dictate the length of the diving ladder required, where a permanently fixed internal personnel ladder does not exist.

Consider tank contents with respect to their effect on divers or equipment planned for operation within the tank. Examples of this consideration include elevated water temperatures which might contribute to hyperthermia in working divers or otherwise induce malfunctions to temperature-sensitive electronics in some ROV's. Conversely, it is also important to consider what effects, if any, the divers or equipment may have on the tank contents. This is particularly true where the chemistry or purity of the tank contents are important.

After completing all planning preparations for tank entry, consider the following specific considerations with respect to the commencement of inspection operations.

Prior to the divers' initial tank entry, ensure that a lifting line, such as that from a crane boom or A-frame with block & tackle, is positioned directly above the tank point-of-entry, and can be lowered quickly into the tank and attached to an unconscious diver. As previously mentioned, a lifting D-ring should be positioned at the top-back of the diver's harness. ready to receive a hook which has been attached to the end of the overhead lifting line.

In the event that a fixed personnel ladder does not exist within the tank, ensure that the diving ladder used is securely fastened at the surface, in such a manner as to minimize its movement both up and down, and sideways, while in use. The ladder's length should allow the lower end to extend 2-3 feet below the surface of the water to facilitate the divers safe and efficient exit from the tank. The ladder's rungs should be of a non-skid configuration, and able to easily support the weight of two (2) men at once. (See section 1.3.6, "Diving Ladder and Stage")

Prior to entering the tank, ensure that the diver's umbilical has been lowered into the tank until the bight of the umbilical is just over halfway to the water's surface.

This amount of slack will minimize the chance of injuring the diver, should he slip and fall while descending the ladder, while preventing him from submerging far below the surface.

The first task to be performed upon initial entry into the tank is the installation of any suction grilles and flow deflectors required. When performing these installations, ensure that the diver approaches both suction and inlet opening from the side, or rear if possible. Ensure that the diver holds the grille/deflector at the ready in front of his body, and secures it in position around the opening as quickly as possible, once arriving in proximity of the opening. Individual tank and piping configurations may determine a optimal order of installation for the devices. Discuss the installation order with the diving supervisor. In general, it may be desirable to install suction protectors first, in descending order according to flow volumes, as large suction openings represent the greatest potential hazard.

If the marking of tank walls, floor, or structures is required, waterproof underwater markers are available from a number of vendors. Note that the ink from these types of markers may not adhere well in tanks where water temperatures are excessively warm. In such cases, some other marking method maybe required, such as scribing of the metal surfaces with an awl.

Where templates, such as those which might define an inspection grid, need to be held in place, small suction cups attached to the template work well for temporarily securing a template to a relatively flat surface. When using a template to perform a large area inspection, the ease and accuracy of the inspection may be increased by using two smaller templates which can be 'leap-frogged''. Thus, the previously inspected position is maintained while the 2nd template is fitted into place to begin the inspection of the next adjacent area. After completing the inspection of that area, the 1st template is then removed from its starting position and fitted into a position adjacent to the previously inspected area, relative to the 2nd template, and so on.

When planning a visual inspection pathway, consider formulating an inspection route which would allow the tank bottom to be inspected last. This will minimize turbidity in the water caused by the disruption of any sediment which might have accumulated on the tank bottom. Also, caution the diver to move slowly when near bottom, to avoid disrupting this sediment prematurely.

There are two principal operational considerations for the inspection of tankage using an ROV; the first is successful navigation, and the second is maintaining adequate visibility for the ROV pilot and/or top side inspector.

With respect to the first consideration, ensure that the ROV pilot is thoroughly familiar with the tank interior configuration and structures. Accomplish this by completely reviewing related drawings of the tank interior with the ROV pilot, for the purpose of developing a rigidly structured inspection pathway for the ROV, until such time as he has thoroughly demonstrated his appreciation of the inspection pathway and attendant structures.

With respect to the second consideration, ensure that the ROV is ballasted to be slightly positively-buoyant. This will allow the ROV operator to use only a small amount of upward thrust when inspecting near the tank bottom. This will minimize the disturbance of any sediment which may have accumulated in the tank,and which would diminish available visibility if disturbed by a burst of downward thrust necessary to decrease the ROV's depth.

4.11 ROV Visual Inspection of PWR Vessel and Removable Internals

4.11.1 Introduction

The PWR vessel and its internal structures require periodic inspection for damage or surface deterioration of components. Location of loose parts, foreign objects, and other debris are also part of the survey. Remotely-operated vehicles (ROV's) can be used to conduct effective visual inspections of PWR vessels and their removable internal structures. Those inspection areas include:

- Reactor vessel vertical wall
- Lower radial support structures
- Nozzles in the reactor vessel wall
- Reactor vessel flange surface and gasket groove
- Reactor vessel bottom head and instrument penetration walls
- Upper core plate alignment pins
- Lower radial support keys
- Secondary core support assembly
- Baffle plates and lower fuel pins
- Thermal shield
- Core barrel outlet nozzle
- Upper internals assembly
- Top of core barrel flange and core hold down spring
- Head and reactor vessel alignment pins

Maintain a video log in conjunction with the inspection information gathered throughout the course of the inspection. Record the following information for each video log entry:

- Video footage number, taken from video tape recorder counter, for each facet of the inspection report.
- Location of the ROV within the reactor.
- Time of day.
- Subject of video image recorded

During the reactor vessel internal examination, location of loose parts, foreign objects, and other debris is probable, in such areas as the:

- bottom of the lower head assembly
- top of the lower core plate
- secondary core support areas

While debris removal is not addressed in these inspection guidelines, it may be convenient to utilize a manipulator-equipped ROV for the inspection, in order to begin removing debris after completing the inspection process. Debris removed from the reactor vessel by the ROV can be transferred directly to an underwater container suitable for storage and transport of such materials.

4.11.2 Equipment

The equipment spread will include a minimum of the following components:

- ROV system, including pan & tilt video camera, quartz-halogen lighting, manipulator, depth pressure transducer, standoff assembly, umbilical, hand controller, system console, and power supply
- Video cassette recorder (VCR) and cassettes
- Video monitor
- 10 mil (0.010") video focus calibration wire
- Weighted plumb line

Select an ROV system having a minimum equipment package as outlined for inspection vehicles in Section 2 of this guide. The ROV itself must be small enough to navigate easily throughout those areas to be surveyed, and, if the vehicle is to be used for either the plumb line repositioning or debris removal, it must also have sufficient payload capacity and manipulator capabilities to accomplish each of those tasks. Additional information on each of these items can be found in Appendix II of this guide.

Because of the high radiation levels encountered inside the reactor vessel, the performance of solid state cameras begins to degrade after continuous exposure to a high rad-field overtime. If this should occur, guide the ROV to a low radiation area and "park" it intermittently during the inspection. Allow sufficient time for the camera optics time to recover. Alternatively, use a radiation-tolerant camera which will generally withstand up to 10^8 rad fields. Use quartz-halogen type lighting onboard the vehicle to provide clear white light sufficient to properly illuminate the inspection areas. ROV's with insufficient lighting arrays will require deployment of auxiliary underwater lighting.

To prepare for the inspection, equip the ROV with a pair of standoffs securely mounted on either side of its video camera. Each standoff should reach forward 18 inches, below and in front of the ROV. Mount an axle fitted with small wheels at either end, between the extended ends of each standoff. This provides a constant inspection distance from the wall surface, as well as a free-rolling wheel in contact with the wall. The length of the axle should be equal to the width of the ROV camera's field of view at 18 inches, which is normally 18-24 inches. Maintain minimal forward thrust to keep the ROV in firm contact with the wall, while using the vertical thruster to move the ROV up and down its survey path. Secure the 10 mil video focus calibration wire to the cross axle, in a position which will allow reference and viewing by the ROV camera. If desired, secure a graduated rule or other representation such as a grayscale to the axle, below and in front of the video camera. This provides a graphic relationship to assist in the description of any anomalies found during the inspection.

Select a VCR which possesses both a 'pause' feature and footage counter. These features will enable the data recorder to conserve video tape during periods of inactivity, and to reference the video tape to the inspection log. Have sufficient video tape cassettes on hand to record planned operations, plus a spare as a contingency in the event of a defective cassette.

Select a video monitor which is compatible with the VCR, and provides a high-resolution screen capable of clearly resolving the chosen reference scales. Separate brightness and contrast controls enabling the data recorder to adjust picture quality are also desirable. An anti-glare screen coating is preferable, though not required.

A 10 mil reference wire, to be used in focusing the video camera and for comparison to surface anomalies, is required.

Keep a plumb line, constructed of 1/8-in. to 1/4-in. polypropylene rope and weighted at one end with a five pound (5-lb.) lead or stainless steel weight, on hand to facilitate positioning of the ROV during the reactor vessel wall inspection. The line should be of sufficient length to reach from the bottom of the reactor to either the refueling crane block, or reactor flange stud holes, depending upon whether the crane or ROV is used to reposition the plumb line. The length of the plumb line required is determined by the above method used. If the ROV is to be used to reposition the plumb line, attach a small buoy sufficient to support the weight of the hook to the plumb line approximately 5' from the hook. This will prevent the hook and rope assembly from falling to the bottom of the reactor, should the ROV lose control of the hook during repositioning. The plumb weight used must be large enough to plumb the line, while remaining within the ROV's payload capacity to reposition easily.

4.11.3 Procedures

Begin the internal inspection with a general visual survey of the reactor's vertical wall. To inspect the wall surface in a systematic manner, use a reference system which will allow the ROV operator to easily maintain his course and judge his position. This may be accomplished in one of the following ways, by using a weighted plumb line extending down the reactor vessel wall to the bottom of the vessel.

- If the use of the refueling crane can be scheduled in conjunction with this inspection, a plumb line can be attached to its block, and maneuvered around the circumference of the reactor vessel as necessary.
- Where the crane is unavailable for use, the top of the plumb line may be fitted with a simple hook which a manipulator-equipped ROV can place into the reactor vessel stud holes around the vessel's circumference.

In either case, use the reactor vessel stud holes as the primary set of reference points for the inspection. Select a starting point and position the plumb line vertically against the reactor wall, adjacent to the selected stud hole. Develop a depth marking system, such as color coded tape markings, for the plumb line, to provide a vertical reference verification for the ROV depth pressure transducer.

Having selected a reference positioning method, begin the inspection procedure as follows:

- Deploy the weighted end of the plumb line into the reactor vessel, either manually, or using the ROV. Position the line adjacent to the reactor vessel stud hole selected as the starting point. Use the same stud hole as a permanent starting point for all future operations, to provide continuity in both the inspection and recording of inspection information. Lower the plumb line to the bottom of the reactor vessel, and attach the top end to the crane, or transfer to the ROV's manipulator for insertion in the desired stud hole.

- Guide the ROV to a position in front of the plumb line, at the top of the vessel wall, and visually scan down the length of the plumb line to ensure it is hanging straight, is in proper position relative to the selected stud hole, and is not fouled.

- Guide the ROV forward towards the plumb line at the top of the wall, until the right traveling wheel contacts the wall just to the right of the plumb line. Minor forward thrust is maintained to ensure continuous contact with the wall. The plumb line should now be located just inside the right traveling wheel track of the ROV.

- Perform any calibration adjustments to the ROV and its systems, such as resolution of the reference scales and adjustment of the variable lighting intensity to maximize video acuity. Adjust the video camera pan/tilt to a forward and 20^{o} down attitude for the downward inspection. The camera tilt should be readjusted accordingly, to a 20^{o} up attitude for ascending inspections.

- Begin this, and each subsequent vertical scan, by noting the depth, reference location, and direction of travel of the ROV.

- Slowly engage power to the vertical thruster until an appropriate downward rate of travel is achieved, sufficient to allow for the accurate inspection of the vessel wall area in view.

- Upon reaching the drop weight at the bottom of the plumb line, stop the descent of the ROV and reverse the forward thruster to back off slightly from the surface of the wall. Guide the ROV laterally to the right, and reposition the ROV's left traveling wheel just outside of the plumb line. This prepares the ROV position for the ascending scan, encompassing the next adjacent field of vision on the reactor wall area.

- Apply minor forward thrust to recontact the traveling wheels on the reactor wall, and reposition the video camera to a 20^{o} up attitude for the ascending scan.

- Slowly engage power to the vertical thruster until an appropriate upward rate of travel is achieved, sufficient to allow for the accurate inspection of the

- Upon returning to the top of the plumb line, withdraw the ROV from its contact position with the reactor wall and reposition the plumb line. If this is to be accomplished with the crane, use the ROV to verify the repositioning of the plumb line in front of the next appropriate stud hole to the right [clockwise]. If using the ROV for repositioning the plumb line, use the manipulator to withdraw the hook from the stud hole, and, counting successive stud holes to the right [clockwise], reposition the hook. Repeat the inspection procedures until the entire vessel wall has been surveyed.

- During the course of the inspection, record any anomalies found, giving their description and exact location as a function of depth and reference points. Reference the footage count, from the video cassette, at the point where the image begins.

The number of stud holes [distance] which can be moved with each relocation is dependent upon the field of vision provided by the ROV inspection system devised. The two variables which effect the relative field of vision are:

- Camera system used

- Distance to reactor wall surface determined by standoff length

The wider the ROV's field of vision, the greater the distance which can be covered in each pair of vertical scans. The length of the standoffs is also related to the ROV camera, in that they are limited in length by the cameras capability to accurately resolve a required image.

After completion of the reactor vessel wall inspection, prepare to remove the plumb line from the reactor vessel. If this is to be accomplished by the crane, guide the ROV to a position where it can scan the length of the plumb line as it is being recovered, to ensure that the plumb line does not become fouled as it is being removed. If the ROV is to retrieve the plumb line, use the ROV to remove the top hook from the last inspection point, and transfer it to an extension tool manipulated from the surface. As surface personnel manually recover the plumb line, use the ROV to once again monitor the extraction of the line to guard against unintentional fouling.

From this point, guide the ROV to the lower radial support elevation, and perform a visual inspection of the vessel radial support block to the vessel shell attachment weld. Examine the clevis insert guide surfaces, attachment bolts, and locking welds at each of the four radial support locations.

For examination of the nozzles in the reactor vessel wall, guide the ROV to the nozzle elevation. At this location, there are a number of nozzles of up to three different types to be inspected, depending upon the particular reactor design and manufacturer:

- 'A' & 'B' Loop outlet nozzles (24)

- 'A' & 'B' Loop safety injection nozzles (0-2)

- 'A' & 'B' Loop inlet nozzles (24)

To examine the outlet nozzles, guide the ROV into the nozzle itself, and inspect the surface of the nozzle to the safe end weld. Finish by examining the outlet nozzle juncture with the reactor wall.

To examine the safety injection nozzles, guide the ROV to the nozzle and inspect the inside surface of the nozzle. Complete the inspection by withdrawal of the ROV sufficiently to inspect the nozzle extension at the juncture of the reactor wall.

To examine the inlet nozzles, begin by inspecting the surface of the nozzle. Complete the inspection by guiding the ROV on an inspection of the inside nozzle radius at the juncture of the reactor vessel wall.

To examine the reactor vessel flange and gasket groove, guide the vehicle to that location, and inspect all accessible surfaces. Begin by selecting a reference point, such as a guide pin, and scan the entire upper surface of the flange from that location . Proceed to guide the ROV around the top of the flange in a detailed inspection of the flange surface. Pay particular attention to the surface of the gasket groove. Examine each gasket clip location and each flange leak-off port.

To examine the reactor bottom head and instrument penetration welds, guide the ROV to a location aligned between one set of inlet and outlet nozzles, and then maneuver the ROV to a position approximately 29" from the bottom head. Maintain this position using the vertical thruster. Scan the bottom head and inspect an area up to and including the bottom head to shell weld. Examine each of the bottom head penetration welds, and the inside surface of the lower vessel head for loose parts, foreign objects, and other debris.

To examine the upper core plate pins, maneuver the ROV inside of the core barrel, to the upper core plate elevation. Examine the upper core plate alignment pin guide surfaces on each of the four pins.

To inspect the lower radial support keys, guide the ROV outside of the core barrel, to the lower radial key elevation. Examine the key guide surfaces and key to saddle attachment welds, on each of the four keys.

To examine the secondary core support assembly, guide the ROV to that area, and inspect the support columns search of the tie plate fasteners [bolts], and locking Welds.

To inspect the baffle plates and lower fuel pins, guide the ROV inside the core barrel to their location. Inspect each of the fasteners, and examine the gap between each of the baffle plates to determine if they are sufficiently small. Examine the keened areas' on the baffle plates. Then, guide the ROV near the lower core plate elevation and examine a representative number of lower fuel pins.

To inspect the thermal shield, guide the ROV outside of the lower internals assembly, to the thermal shield lower support elevation. Examine the thermal shield flexures and accessible attachment bolts at each of the six lower support locations. Reposition the ROV to the thermal shield upper support elevation, and examine the upper support bolts at each of the upper support locations. Complete the inspection by examining each of the adjustment plugs.

To examine the core barrel outlet nozzle, guide the ROV outside the lower internals assembly, to the core barrel outlet elevation. Examine the core barrel outlet nozzle bearing surfaces at each of the two nozzles.

To inspect the upper internals, guide the ROV to the outside of the upper internals assembly and examine a representative number of support columns and guide tubes, looking for obvious deformation. After completion of this task, reposition the ROV near the upper support plate elevation and inspect the accessible guide tube flange bolting. Determine if all locking welds on each bolt head are intact. Complete the inspection by examining the thermocouple conduits to determine if they are intact.

To examine the top of the core barrel flange, guide the ROV into a position to examine the area, paying particular attention to the top of the flange at the core hold down spring seating surface. Guide the ROV into the core hold down spring location and inspect all accessible seating surfaces.

To inspect the head and vessel alignment pins, position the ROV outside the lower internals, near the core barrel flange elevation. Examine the guide surfaces, as well as the attachment bolts and locking welds, on each of the four head and vessel alignment pins.

This concludes the ROV reactor vessel and internal structures inspection. If desired, the ROV may also be positioned to inspect the underside of both the upper internals assembly and secondary core support, prior to each being placed in its stand. This would allow examination of both lower guide tube support pins and a representative number of upper fuel pins, and, accessible secondary core support components and fasteners, respectively.

Chapter 5

Appendixes

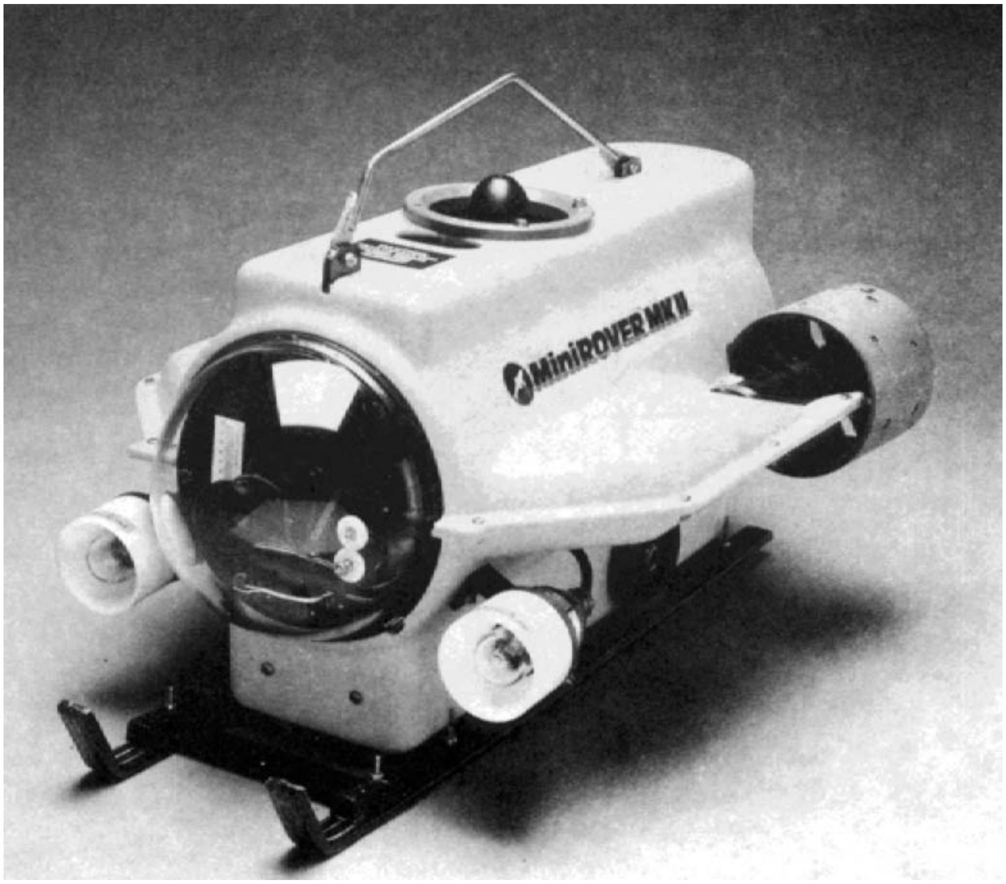
COMPANY	ADDRESS	CITY	ST	ZIP	PHONE	CONTACT
2-W Diving, Inc.	753 Winthrop St.	Mt. Pleasant	SC	29464	803-881-1766	Gary Weaks
ABS Marine Towing & Salvage Ltd.	81 Lighthouse Rd.	Babylon	NY	11702	516-587-8346	Bruce Sweet
Acadiana Divers & Salvage, Inc.	P. O. Box 90192	Lafayette	LA	70509	318-232-8714	James Rawla, III
A. H. Powers, Inc.	5800 40th Avenue West	Seattle	WA	98199	206-283-9996	A H. Powers
Allen Marine Services, Inc.	P. O. Box 86	Orchard Park	NY	14127	716-662-9229	Frank Holden
Allied Commercial Divers	N. 6522 Whitehouse	Spokane	WA	99208	509-467-8400	Dave Darlow
American Diving & Salvage	3431 N. Damen	Chicago	IL	60618	312-337-0688	Harry Zych
American Oifield Divers, Inc.	130 East Kalisle Saloom	Lafayette	LA	70508	318-234-4590	Sonny Freeman
American Underwater Contractors, Inc.	3426 Forester Rd.	Bridgeton	MO	63044	314-739-5235	William Dover
Anchor Marine Services, Inc.	P. O. Box 3503	Tequesta	FL	33469	407-845-6381	Thomas Roam
Aqua Tech Marine Construction	P.O. Box 40	Warren	ME	04864	207-273-3699	James Curry
Aquatic Sciences Inc.	Box 2205, Station B	St. Cathaines	ONT	L2M GPG	416-641-0941	Blake Goulet
Associated Marine Divers, Inc.	13830 Burgayne Lane	Houston	TX	77077	713-556-1809	Douglas Maddox
Atlantic Construction & Marines, Inc.	P. O. Box 3582	Savannah	GA	31401	912-355-9561	Alton Coursey
Atlantic Diving & Marine Contractors	3330 River Road	Wilmington	NC	28402	919-791-2411	Michael McCarley
Atlantic Diving & Welding Co.	P. O. Box 302	Branford	CT	06405	203-488-0206	Robert Barba
Atlantic Underwater	901 Cracker St.	W.Palm Beach	FL	33413	407-686-7066	Richard Easton
Cal Dive International	13430 NW Fwy, Ste 350	Houston	TX	77040	713-690-1818	Jerry Reuhl
Caldwell's Diving Co., Inc.	P. O. Box 401	Toma River	NJ	08753	908-244-0747	James Caldwell, Sr.
Can-Dive Marine Services Ltd.	#3 1225 East Keith Road	N. Vancouver	BC	V7J 1J3	604-984-9145	Phil Nuytten
Casper Coldsimo & Son, Inc.	5170 Campbells Run Road	Pittsburgh	PA	15205	412-787-1268	James Gearhart
Central States Underwater Contracting	4705 Merriam Drive	Overland Park	KS	66203	913-262-2155	Donald Doleshal
Clark Maritime Corp.	P. O. Box 838	Mercer Island	WA	98040	206-783-6699	Ginny Clark
Coastal Marine Services	17 Persimmon Ct.	Petaluma	CA	94954	707-762-1573	Rick Heaslet
Collins Engineers, Inc.	165 N. Canal St. Suite 975	Chicago	IL	60606	312-454-1060	James Rose
Commercial Diving Service, Inc.	P. O. Box 360568	Columbus	OH	43236	614-258-2000	Jon Hazelbaker
Commercial Diving, Inc.	13 132nd St.	Chesapeake	WV	25315	304-949-5771	Dan Meadows
Complete Diving Services, Inc.	57 Sanford Place	Jersey City	NJ	07307	201-222-5408	Kathy A. Young
Continental Diving Services	P. O. Box 2484	Morgan City	LA	70381	504-395-5251	Don Pearson
Crofton Diving Corp.	16 Harper Avenue	Portsmouth	VA	23707	804-397-1131	Juan Crofton
Dive Boat	P. O. Box 12	Portland	ME	04112	207-772-7277	Lloyd Covens
Dive Masters, Inc.	15 Pumpshire Rd.	Toms River	NJ	08753	908-270-2000	John Masters
Dive-Tech International	6200 Eighty Ave. N.	Pinellas Park	FL	34665	813-541-1102	Victor Griswold
Diving Dynamics	#6 2070 Harvey Avenue	Kelowna	BC	V7Y 8P8	604-861-1848	Vera Johnston
Diving Services International	P. O. Box 2641	Owensboro	KY	42302	502-685-9002	Marshall Whitmer

COMPANY	ADDRESS	CITY	ST	ZIP	PHONE	CONTACT
DonJon Marine Co.	1250 Liberty Ave.	Hillside	NJ	07205	908-964-8812	John Witte, Jr.
DRS Marine, Inc.	1378 Lemon St.	Valleja	CA	94590	707-648-3483	Richard Williams
Dryden Diving Co., Inc.	325 Russell McGill Road	Swedesboro	NJ	08085	609-467-1385	Donald Dryden
Eason Diving & Marine Contrs., Inc.	P. O. Box 70040	Charleston	SC	29415	803-747-0548	Thomas Eason
Emark Ind./Marine Division	S-3566 Benzing Rd.	Orchard Park	NY	14127	716-662-1704	Gary Shoreq
Epic Divers, Inc.	1556 MacArthur Ave.	Harvey	LA	70058	504-340-5252	Julie Rodriquez
F.U.R.E.I./Fathom Undersea	P. O. Box 99	Spanish Fort	AL	36527	205-626-7800	Jon Meshejian
G & G Marine, Inc.	25933 Budde Rd.	Woodlands	TX	77380	713-367-8352	Ross Saxson
Geddes Diving & Salvage, Inc.	20169 Pineville Road	Long Beach	MS	39560	601-863-0484	Glenn Geddes
General Construction Co.	P. O. Box 24505	Seattle	WA	98124	206-938-6755	Ronald McCray
General Offshore Corp.	P. O. Box 21726	Ft. Lauderdale	FL	33335	305-989-2188	Jim Byous
Global Diving & Contractors	P. O. Box 31570	Lafayette	LA	70593	318-988-5176	Jim Dore
Global Diving & Salvage, Inc.	2763 13th Ave., SW Harbor Island	Seattle	WA	98134	206-623-0621	Tim Beaver
Graphic Underwater Engineering & Diving Inc.	12790 Beaubian Rd.	Jacksonville	FL	32258	904-260-9375	Robert Bernhardt
Gulf Coast Marine Divers	P. O. Box 1379	Abbeville	LA	70511	318-893-5116	Reed Bohn
Guthrie Diving Services	P. O. Box 36	Worthington	PA	16262	412-548-7541	Marlin Guthrie
H.E.A. Associates, Inc.	235 Monhagen Ave.	Middletown	NY	10940	914-343-4040	Harold Anderson
H. J. Merrihue Commercial Diving	P. O. Box 23123	New Orleans	LA	70183	504-468-2800	Chad Byard
$H_2$0 Divers, Inc.	P. O. Box 75408	Tampa	FL	33875	813-247-5555	Mike Weldon
Han Padron Associates	Eleven Penn Plaza	New York	NY	10001	212-736-5466	Michael Delaney
Handon Diving Services, Inc.	1218 Irving St. NE	Washington	DC	20017	202-529-1809	Mark Handon
Holland Diving Service	P. O. Box 939	Decatur	AL	35602	205-353-2940	Gibson Holland
Hollister Marine Commercial Diving	P. O. Box 472	Lamont		60439	708-839-1494	Scott Hollister
Hudson River Towing & Salvage	P. O. Box 666	Nyack	NY	10960	914-353-1559	Steven Trueman
Hydro Corporation	P. O. Box 13048	Charleston	SC	29412	803-762-6423	Michael Hays
Ideal Marine Services, Inc.	12700 S. W. 81st Avenue	Miami	FL	33156	305-252-1819	John Thompson III
Inland Divers	3140 S. Winston, Ste. 2	Tulsa	OK	74145	918-747-7776	Kenneth Nix
Inner Tech Commercial Diving	P. O. Box 9123	Warwick	RI	02886	401-521-2500	Thomas Post
Inshore Divers, Inc.	2102 Kelley Court, Unit C	Pittsburg	CA	94565	415-439-7227	William Aichele
Intercoastal Diving, Inc.	5659 Market Street	Wilmington	NC	28405	919-395-5211	Stanley Rudd
International Underwater Contractors	P. O. Box 205	City Island	NY	10464	718-885-0699	Andre Galerne
KWJ'A Diving Corporation	P. O. Box 906	Montchapain	DE	19710	302-479-5235	Hans Ploeg
Lake Erie Diving & Construction	7224 Industrial	Mentor	OH	44060	216-942-3814	Patrick Murphy

COMPANY	ADDRESS	CITY	ST	ZIP	PHONE	CONTACT
Lakes & Rivers Contracting, Inc.	P.O.Box67	Lamont	IL	60439	708-739-2460	John Petrokovich
Lane-Robinson Associates, Inc.	29 Boston Post Road	East Lyme	CT	06333	203-444-6050	David Robinson
Lares Undersea Contractors	4740-B Franchise Street	Charleston Heights	SC	28418	803-552-3337	Kenneth Jensen
Lea Diving & Salvage Co., Lnc.	P. O. Box 314	Mobile	SL	36601	205-476-9174	Kim Lea
Lewis Diving & Salvage, Inc.	1020 Ginnin Road	Jacksonville	FL	32225	904-221-0221	John Lewis
LIPS Propellers, Inc.	3617 Koppens Way	Chesapeake	VA	23323	804-485-5275	John Kennedy
LOCK7	Rt. 2, Box 357A	Wagoner	OK	74467	800-321-3483	John Crows
Lomax Marine Construction, Inc.	RR2, Box 50	Lepreau	NB	EDG 2H0	506-659-2021	Hal Lomax
Los Osos Engineering Inc.	P. O. Box 6749	Los Osos	CA	93412	805-528-7969	Ed Swenson
M. G. McLaren, P. C.	100 Snake Hill Road	West Hyack	NY	10994	914-353-6400	Malcolm McLaren
Mainstream Commercial Divers	P. O. Box 1428	Murray	KY	42071	502-753-9654	Craig Fortenberry
Marine Drilling & Blasting, Inc.	2743 Bernon Terrace #8	Jacksonville	FL	32247	904-387-4784	Murray Black
Marine Service Unlimited	16044 33rd Ave., NE	Seattle	WA	98155	206-364-8975	Carl Erick
Marine Service Commercial Divers	P. O. Box 258	Chula Vista	CA	91912	619-422-8918	Tom Devine
Marion Hill Associates, Inc.	P. O. Box 252	New Brighton	PA	15066	412-847-3483	Richard Riley, Jr.
Maryland Diving Service, Inc.	1903 Gwynn Oak Avenue	Baltimore	MD	21207	410-298-4471	Charles Warren
McDermott, Inc.	P. O. Box 188	Morgan City	LA	70381	504-631-8735	Jim Mullen
Mid Atlantic Diving Contractors	3275 Bethany Lane	Ellicott City	MD	21042	800-628-3014	Bruce Trader
Midwest Diving Service	3215 Madison St.	Omaha	NE	68107	402-733-4232	Gordon Gammel
Midwest Marine	19920 W. 161st St.	Olatha	KS	66062	913-829-4488	Michael McGovern
Miller Divers, Inc.	P. O. Drawer 1003	Fairhope	AL	36533	205-928-2526	J. Ray Miller
Muldoon Marine Services, Inc.	P. O. Box 3223	Terminal Island	CA	90731	310-548-1822	Richard Barta
Need-A-Diver Marine Services, Inc.	1 Barge Avenue	Tampa	Fl	33605	813-247-1146	Herman Haney
North Coast Divers, Inc.	1370 Industrial Avenue, Suite F	Petaluma	CA	94952	707-762-1575	Alick Heaslet
Northeast Marine Service	25 Depot Road	Falmouth	ME	04105	207-829-6911	Joseph Stanley
Ocean Corp.	10840 Rockley Rd.	Houston	TX	77009	800-321-0298	Les Joiner
Oceaneering International, Inc.	16001 Park Ten Place, Ste 600	Houston	TX	77218	713-578-8868	Steve Helburn
Parsons Brincherhoff Quade & Douglas	4200 W. Cypress, Suite 700	Tampa	FL	33607	813-874-5300	David Severns
Phoenix Diving, Inc.	P. O. Box 53907	Lafayette	LA	70506	318-237-1444	Mark Hill
Podesta Divers & Construction	Pier 26-Embarcadero	San Francisco	CA	94105	415-495-3955	Mark Forbert
Poly-Hydro Marine	1090, rue Louis Riel	Sainte-Foy	QUE	G1W 4AB	418-651-3011	Pierre Lariviere
Portland Diving Services, Inc.	P. O. Box 8796	Portland	ME	04104	207-725-5811	William Blood

COMPANY	ADDRESS	CITY	ST	ZIP	PHONE	CONTACT
Poseidon Subsea Services, Inc.	P. O. Box 6336	Corpus Christi	TX	78466	512-852-6220	John A. Gault
Pro-Dive, Inc.	P.O.Box663	Ottawa	IL	61350	815433-5228	Randy Jones
Professional Divers/New Orleans	1802 Engineers Rd.	Belle Chasse	LA	70037	504-391-1351	F.L. Tomlinson
Professional Divers Service	1135 Pittsburgh St.	Springdale	PA	15144	412-274-7719	Richard Geyer
Professional Divers Hawaii, Inc.	P. O. Box 1252	Kamuela	Hi	96743	808-883-9500	Douglas Carr
Randive, Inc.	259 Oak Avenue	Staten Island	NY	10306	716-987-5858	Curt Erlandson
Reeks Diving Co., Inc.	9755 Arberly Drive	Dallas	TX	75243	214-644-6321	Jim Reeks
Riverside Towing	Rt26, Box 23	Piesis	NY	13675	315-462-2812	Alan Hoover
ROV Technologies, Inc.	605 Lapalco Blvd.	Gretna	LA	70056	504-394-1355	Drew Michel
Russell Veteto Engr.	P. O. Box 2927	Corpus Christi	TX	78463	512-887-8851	Patrick Veteto P.E.
S&J Diving & Marine	P. O. Box 34413	Houston	TX	77234	713-488-3483	Stanley Jones
Safe Dive Systems, Inc.	521 Bayou Rd.	Poydras	LA	70085	504-682-0814	Rhonda Martinez
Salmona Dredging Corp.	P. O. Box 42	Charleston	SC	29402	803-722-2921	Richard Galmono
Salvage & Demolition	36 King Cove Rd.	N. Waymouth	MA	02191	617-337-2160	David Bittner
Science Diving Environment	3814 Trade Center. Dr.	Ann Arbor	MI	48108	313-677-0690	Karl Luttrell
Sea Engineering Inc.	Makai Research Pier	Waimanalo	HI	96795	808-259-7966	Patrick Rose
Sea Land Construction & Engineering	P. O. Box 1370	Roswell	GA	30077	404-642-2141	Daniel Deslauriers
Seatech Contracting, Inc.	P. O. Box 2115	Kailua-Kona	HI	96745	808-326-5647	Clay Hutchinson
Seaward Marine Service	5409 Beamon Rd.	Norfolk	VA	23513	804-853-7683	Cecil Achord
Shipcare, Inc.	4787 Crisp Way	San Diego	CA	92117	619-270-7607	Mark Rogers
Sonalysts Diving Service	P. O. Box 280	Waterford	CT	06385	203-442-4355	Karl Thonnes
Sound Marine, Inc.	P. O. Box 5387	Bellingham	WA	98227	206-571-6152	Richard O'Conner
Spearin, Preston & Burrows, Inc.	446 W. 34th St.	New York	NY	10001	212-563-5400	G.A. Neumann, Jr.
Specialty Diving Services, Inc.	208 N. Adams	N. Kingstown	R I	02852	401-295-5256	Ron Archamault
Standard Diving Co.	P.O.Box2013	Hyde Park	NY	12538	914-229-7038	Jim Reilly
Stearns Diving Co.	192 Smith St.	Rockville	MD	20850	301-294-9414	Larry Guthrie
Stroud Diving & Hydrography	2045 Gilmore St.	Jacksonville	F L	32204	904-355-1777	Will Hux
Sub Ocean Technologies	31 Dive Street	Huntington Station	NY	11746	516-873-2817	Greg Hannington
Sub Sea International	701 Engineers Rd.	Belle Chase	LA	70037	504-393-7744	Dennis Jahde
Subsea Associates. Inc.	2313 E. Main St.	Bridgeport	CT	06610	203-368-4611	Richard Jager
The Ocean Corporation	10840 Rockley Road	Houston	TX	77099	800-928-5200	Les Joiner
Titan Maritime Industries	P. O. Box 350465	Ft. Lauderdale	FL	33335	305-929-5200	Guy Wood
T.N.J. Marine, Inc.	P. O. Box 6	Balmar	NJ	07719	908-681-8122	Tom Junay
Townsend & Bottum Service Group	P. O. Box 1187	Ann Arbor	MI	48106	313-761-1855	C.F. Ruegar, Jr.

COMPANY	ADDRESS	CITY	ST	ZIP	PHONE	CONTACT
Underwater Capabilities, Inc.	P.O.Box 6385	Gulf Breeze	FL	32561	904-932-50510	David Mandley
Underwater Marine Contractors, Inc.	5533 Old Brecksville Road	Independence	OH	44131	216-524-0560	Robert Humphrey
Underwater Resources	Pier 26	San Francisco	CA	94105	415-974-5464	Thomas Belchar
Underwater Specialists	Box 1348	Cochrane	ALB	TOL0W0	403-932-3620	N. Walter Jackson
Underwater Tech System	8966 Blue Ash Rd., SH	Cincinnati	OH	45242	513-793-3849	W.O. Larman
United Commercial Diving	54 Cooke St.	Staten Island	NY	10314	718-698-3291	Michael Gugleotti
Utility Diving Services, Inc.	P. O. Box 6149	Kansas City	KS	68106	513-371-0045	Robert Coleshal
United Marine Divers	E. 3923 Boone Avenue	Spokane	WA	99202	509-535-6600	Roger Rouleau
W. J. Castle, P.E. & Associates	P. O. Box 586	Lumberton	NJ	08048	609-261-2268	William Castle
Walker Diving Contractors, Inc.	107 Divers Lane	Laurel Springs	NJ	08021	609-784-2208	Phyllis A. Streit
West Coast Seaworks	1406 Park Street, Suite 100	Alameda	CA	94501	510-521-5577	Scott Francis
Williams & Schultheiss Diving	RR#3, Box 480	Rockport	IN	47635	812-645-5071	Bran Williams

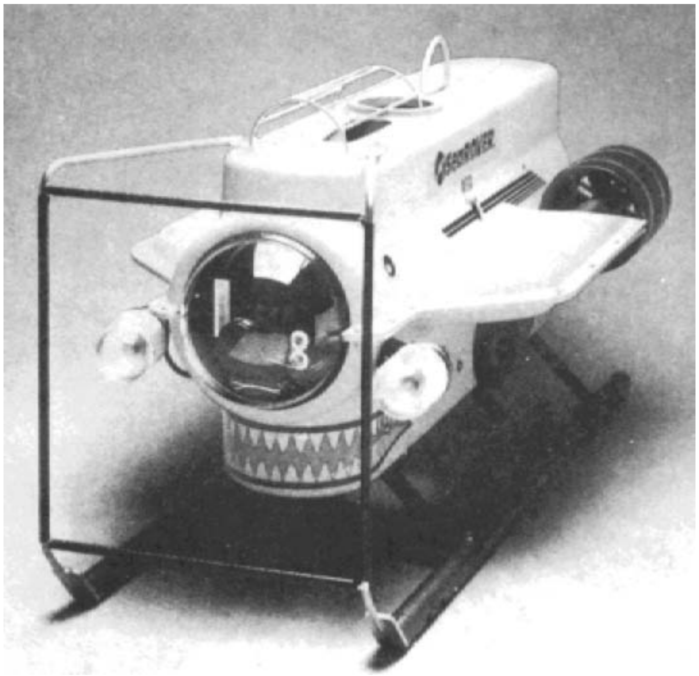


MiniRover Mark II

Benthos, Inc.
Edgerton Drive
North Falmouth, MA. 02556

Depth:	600 fsw	**Speed:**	2.9 kts.
Weight:	75 Ibs./air-slightly positive water	**Size:**	34"x18.5"x16.6"
Camera:	Low-light, hi-resolution color, Auto iris	**Lighting:**	2/150w Quartz-halogen
Temperature Range:	unknown	**Operating Voltage:**	100/120/208/240 vac 50-60 hz 1kw

Payload: 8-12 Ibs. user variable
Instrumentation: Analog compass rose, Depth transducer, Date/Time, Relative altitude
Options:
- Entended depth to 1000'
- Mesotech 971 Scanning Sonar
- Low-light B/W Camera
- 35 mm Still Camera
- High Speed Towing Kit
- Ultra Thrusters
- Manipulator

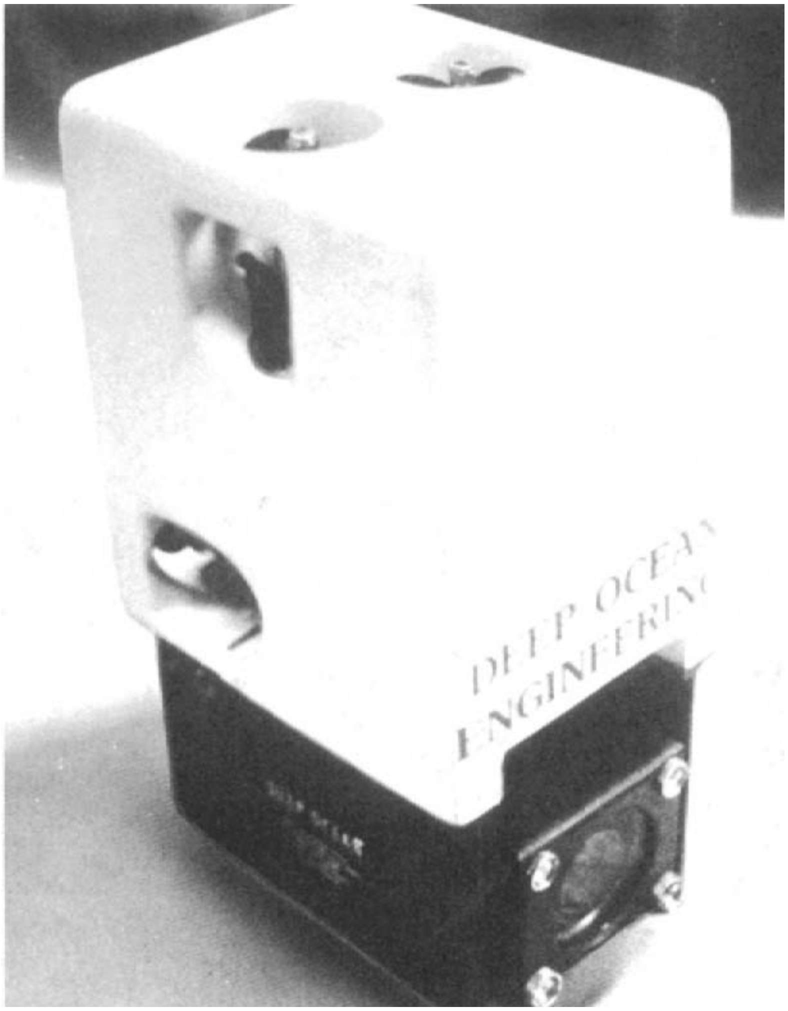


SeaRover

Benthos, Inc.
Edgerton Drive
North Falmouth. MA. 02556

Depth:	1000 fsw	**Speed:**	2.5 kts.
Weight:	175 Ibs./air	**Size:**	56"x27"x25.5"
Camera:	Hi-resolution color. Auto iriis	**Lighting:**	2/150w Quartz-halogen
Temperature Range:	unknown	**Operating Voltage:**	220V 30

Payload: 15-22 Ibs. user variable
Instrumentation: Digital heading, Depth transducer. Date/Time
Options: Ferranti ORE Trackpoint II acoustic positioning
Mesotech 971 Scanning Sonar
- Entended umbilical to 1500'
- Garage/Tether Management Systems
- Monochrome Video Camera
- Low-light B/W Camera
- Manual camera iris
- 35mm Still Camera
- Altimeter/Auto Altitude
- Auto Heading
- Additional Lighting
- Cathodic Protection Probe
- Still camera



FIREFLY

Deep Ocean Engineering
1431 Doolittle Drive
San Leandro, CA. 94577

Depth:	150 fsw	Speed:	unknown
Weight:	10 Ibs./air-slightly negative/water	Size:	12.5"x7.0"X5.5"
Camera:	NTSC-B/W 1/2" Saticon Tube. Auto iris	Lighting:	4/6w mini lamps 2/20w front and rear
Temperature Range:	32°-104° F	Operating Voltage:	110V

Payload: n/a
Instrumentation: n/a
Options:
- On screen display with keyboard
- manipulator

PHANTOM 300

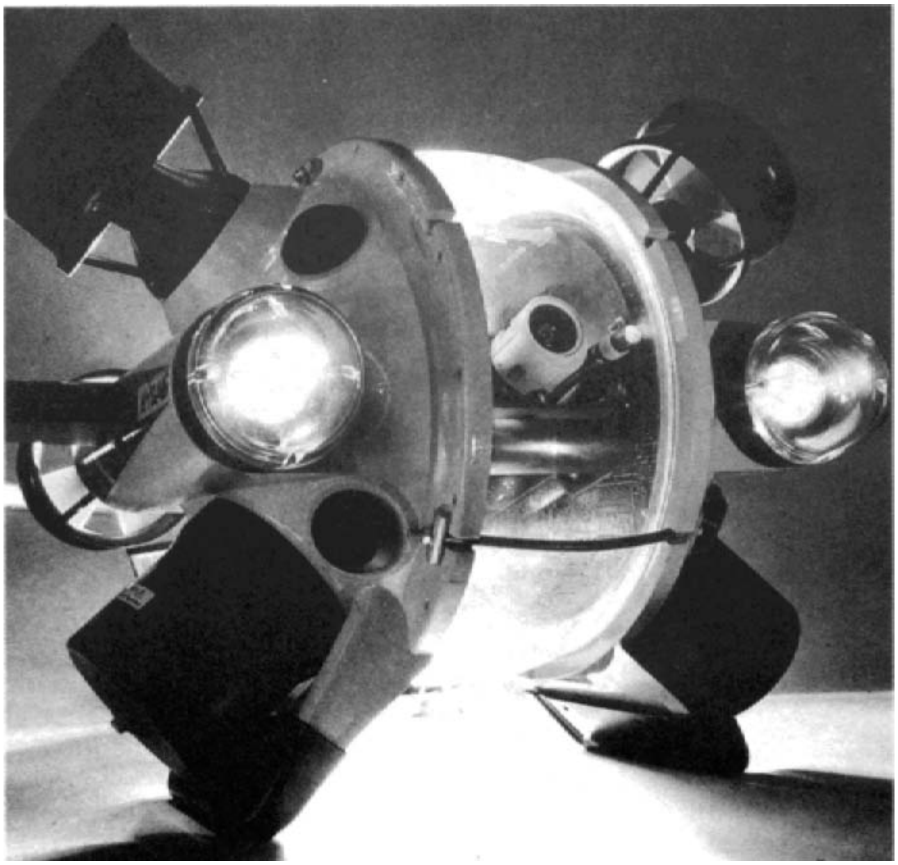
Deep Ocean Engineering
1431 Doolittle Drive
San Leandro, CA. 94577

Depth:	300 fsw	**Speed:**	2 kts.
Weight	71 Ibs./air-slightly negative/water	**Size:**	38"x20"x18
Camera:	PAL/NTSC Color.Auto iris	**Lighting:**	2/150w tungsten-halogen
Temperature Range:	unknown	**Operating Voltage:**	120v-240v 50-60hz 1.2 KVA

Payload: n/a

Instrumentation: Advanced fluid-gimballed flux gate compass, Depth transducer, instrument output port

Options:
- Access to 2/20 gauge conductors in umbilical
- Cathodic Protection Probe
- Still Camera



HYBALL

Pressure Products, INc.
1720 130th Avenue
Suite 103
Bellevue, WA. 98005

Depth:	100 fsw	**Speed:**	2.5 kts.
Weight:	86 Ibs./air-neutral/water	**Size:**	19.09"x25.39"x20.86"
Camera:	CCD B&W or Color	**Lighting:**	2/100w Quartz forward 2/75w on camera
Temperature	unknown	**Operating**	110v-240 10 60-50hz 2.5kx

Payload: 9 Ibs.

Instrumentation: Depth transducer, Compass, Camera position, 360° camera vision, Auto heading, Auto depth, Trim, Rate gyro

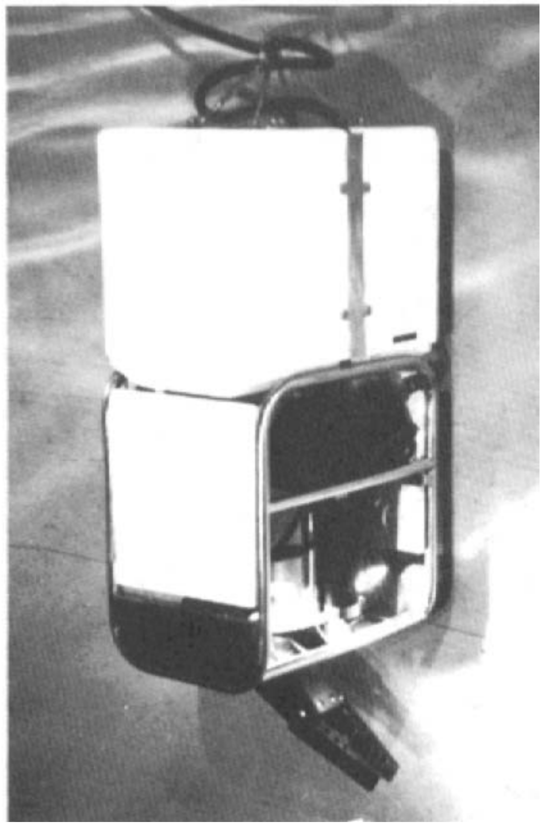
Options:
- Two additional camera capability
- Manipulator
- Cathodic Protection Probe
- SONAR
- Acoustic Tracking System

SEAMOR

RSI Research, Ltd.
9865 W. Saanich Rd.
Sidney, B.C. Canada V8L3S1

Depth:	150 fsw
Weight:	18 Ibs./air-neutral/water
Camera:	CCD B&W or Color
Temperature Range:	23°-140°F
Speed:	2 kts.
Size:	13"x10.5"x9"
Lighting:	100 w Quartz
Operating Voltage:	120v 60hz
Payload:	2 Ibs.
Instrumentation:	Depth Guage, Compass

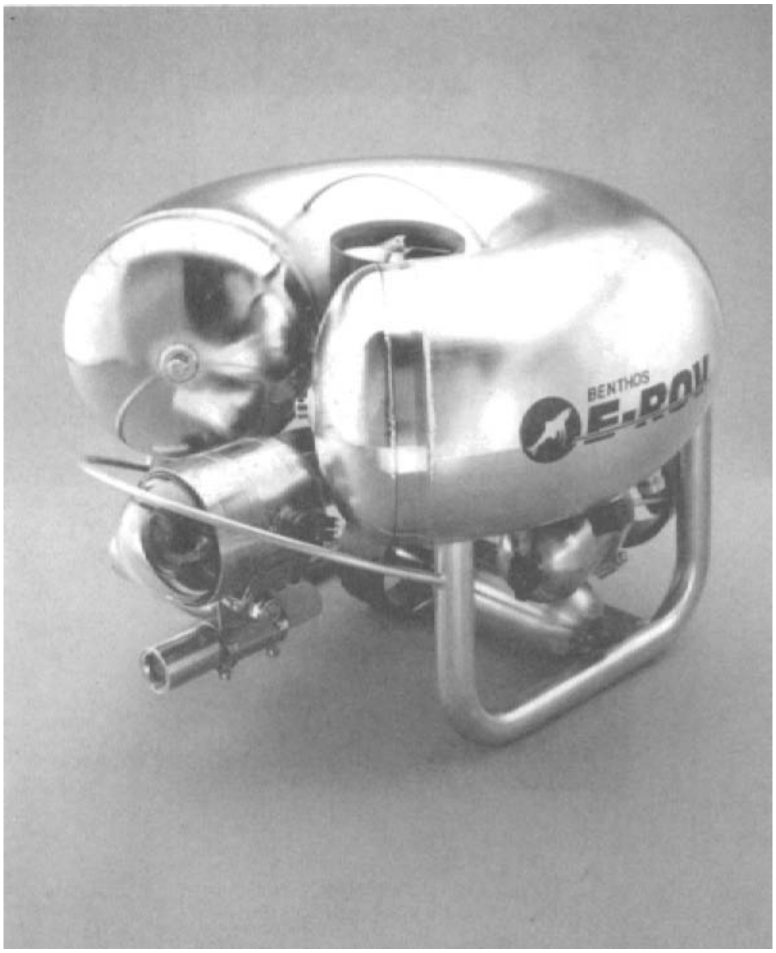
Options:
- Increased Depth Rating
- Single Function Manipulator
- SONY EV-DT 1.5" video c/w video 8mm recorder
- Underwater Tractor Tracks for crawling configuration
- Propeller Guards



ROV1

R. O. V. Technologies, Inc.
P. O. Box 10
Vernon, VT 05354

Depth:	125 Ibs.	**Speed:**	±1 kt.
Weight:	75 Ibs.	**Size:**	13"wx9.5"dx27"h
Camera:	B/W Rad-tolerant to 10^6r/hr. >700 lines horizontal resolution Saticon tube.	**Lighting:**	(<4) variable wattage lights.≤500w each. Temperature - coordinated.
Temperature Range:	≤140°	**Operating Voltage:**	100 vAC 60hz
Payload:	±2 Ibs.		
Instrumentation:	depth transducer		
Options:	color camera video manipulator 3-functions laser-calibrated measurement system computerized video enhancement system S-VHS recording equipment wide angle lens		



E-ROV

Benthos Inc.
49 Edgerton Drive
North Falmouth, MA 02556-2826 USA

Depth:	46 meters/150'	**Speed:**	2 knots
Weight:	3.6 kg/52 Ibs.	**Size:**	19.5"L X 18"W X14.5"H
Camera:	Benthos Model 4206 Color CCD in stainless steel housing	**Lighting:**	150W Variable Intensity Flood
Temperature Range:	N/A 250'	**Operating Voltage:**	15/240VAC 50/60HZ, 3KW
Payload:	2.3 kg		
Instrumentation:			
Options:	Sharps DP System		

Appendix VI

Underwater Repair Welding Guide

Temporary ship repair and underwater salvage work initiated the need for wet welding development in the early 1900s. During WWI and WWII the British and U.S. Navy found extensive use for wet welding repairs for the temporary maintenance and salvaging of battleships. After WWII, wet welding continued to be utilized for ship repair due to the expense and time required for in dry dock repair operations. An increase in offshore drilling in the 1960s brought about another surge in underwater welding development, with permanent repair applications being performed on offshore platforms by the end of the 1970s. By this time, wet welding was no longer considered to be limited to emergency and temporary repairs of noncritical members. In 1983, ANSI/AWS D3.6, *Specification for Underwater Welding,* was published to establish standards for variables related to wet welding of low-carbon and low-alloy steels, which are not covered in normal in-air or surface welding codes or regulations.

Commercial nuclear power facilities have justified the need for implementing underwater wet welding repairs of stainless steels for both temporary and permanent repairs. At this time, due to the practicality of manual shielded metal arc welding (SMAW), it is the only option available for manual underwater wet welding applications, although recent developments have shown flux-cored arc welding (FCAW) is capable of producing results similar to SMAW. The advantage of FCAW is the ability to completely automate the process for applications that are too restrictive for a diver, due to accessibility or radiation levels. FCAW is also capable of continuous welding which generally results in reduced repair time.

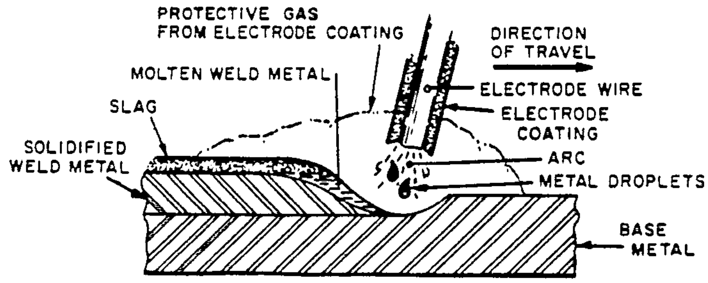
Underwater SMAW

Principles

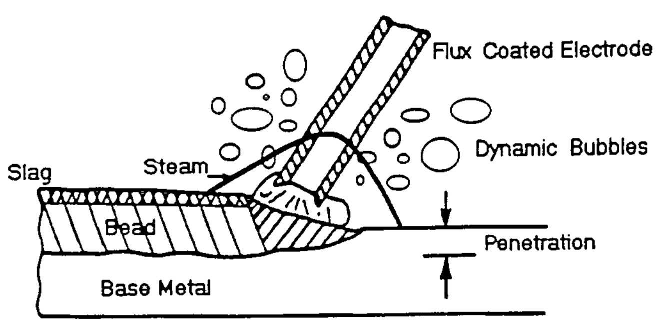
SMAW is the most fundamental and practical welding process available for manual underwater welding operations. The same basic principles required of the SMAW process on the surface, also apply to underwater applications, as seen in Figure VI-la. Welding can be accomplished a great distance from the welding power supply which makes it ideal for most repairs. SMAW is limited to manual operations and accessibility for the diver/welder to the repair location is required, resulting in potential radiation exposure. The basic principles describing the welding process are listed below.

An arc is established between the electrode and the work piece by shorting the electrode with the work piece, producing a surge in current. When the electrode is retracted a column of ionized gas or plasma is formed, sustaining the arc. The heat created by the arc melts the electrode and creates a molten pool which coalesce to form a weld. The flux coating of the electrode melts and decomposes to form a gas shielding. The gas shielding protects the transfer of the molten metal and the molten pool, and assists in stabilizing the arc. The flux coating also forms a slag as the molten pool solidifies, protecting the solidifying metal, scavenging oxygen and controlling the cooling rate. Alloying elements may/also be introduced into the weld deposit through the flux. (Materials section discusses properties of the flux chemistry.)

The effect of water on the process introduces variables that differentiate the behavior of the process in "dry" versus "wet" welding conditions. Water constricts the arc column and weld puddle, quenches the molten material and reduces the effectiveness of the shielding gas and slag. The protective gas around the work area is reduced to a dynamic formation of bubbles, as seen in Figure VI-lb. As a result, the mechanical and metallurgical qualities of the weld and heat-affected zone (HAZ) can be affected. In addition, factors such as restricted visibility, buoyancy and bubble formation/movement introduced by the water tend to compromise the abilities of the diver/welder.



SURFACE SHIELDED METAL ARC PROCESS
Figure VI-1a



UNDERWATER SHIELDED METAL ARC PROCESS
Figure VI-1b

Power Supplies

There are three basic welding power supplies that can be utilized for SMAW.

- Motor generator
- Transformer rectifier
- Inverter

The power supply must be capable of supplying adequate amperage and voltage. A minimum of 200 amperes, preferably 300 amperes or greater, of constant direct current (CC) is usually adequate. If other underwater cutting or gouging processes are to be carried out, in addition to underwater welding, a 400 ampere power supply or greater is needed. Some welding power supplies can be wired in parallel where necessary, to obtain required current levels. Single power sources of adequate capacity are preferred. The capacity and type of power supply depends on the water depth of the work, electrode size, desired weld characteristics (slope of volt-amp curve) and the duty cycle. The power demand for underwater welding is approximately 25% greater than needed for surface welding due to an overall increase in arc voltage for any given current.

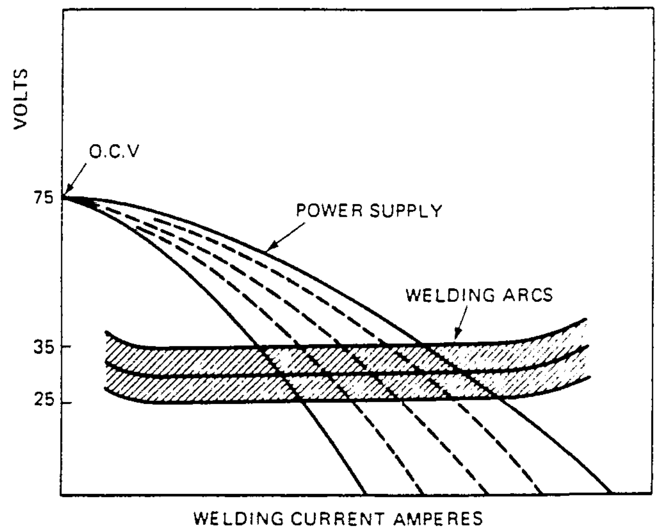
Alternating current (AC) power supplies are not recommended for underwater wet welding. Direct current (DC) has been found to be safer than AC for underwater applications. In addition to safety, DC arc characteristics have a significant advantages over AC.

Advantages of DC welding current include

- DC has better arc starting properties
- DC offers better are stability and operating characteristics with smaller diameter welding electrodes.
- Shorter are lengths are easier to maintain with DC than AC.
- DC is preferred for out of position welding since lower amperages can be utilized.

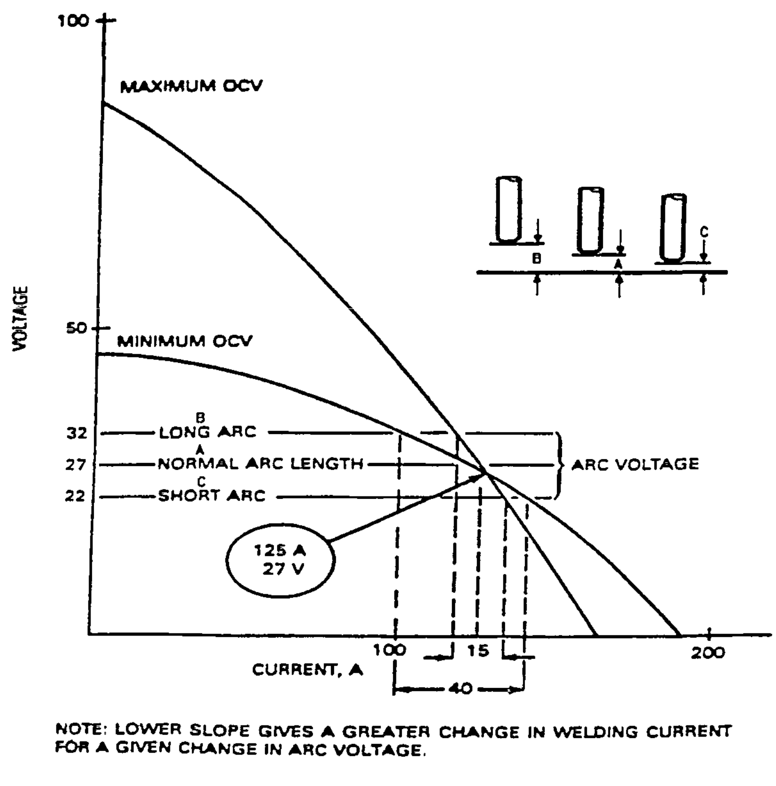
Constant current (CC) power supplies with steep volt-ampere curves are preferred for SMAW because they permit arc lengths (arc voltage) to vary while maintaining the set current level. A constant voltage (CV) machine, on the other hand, limits the variations of arc length and voltage but allows significant changes to occur in the current. CV machines are not desirable for manual SMAW, but are typically employed with the FCAW process.

The current output of a CC power supply can be adjusted by altering the short circuit current, "drooping characteristic," illustrated in Figure VI-2, or by altering the open circuit voltage (OCV). The OCV is the voltage potential prior to the establishment of the arc or welding load, which allows an arc to bridge the gap between the electrode and the work piece. OCV is a characteristic of the power supply and varies per manufacturer and model. By altering the OCV, the slope of the volt-amp curve can be made steeper or more gradual (Figure VI-3).



CONVENTIONAL VOLT-AMP CURVE FOR CONSTANT CURRENT(CC) WELDING POWER SUPPLY

Figure VI-2



VOLT-AMP CURVE WITH VARIATIONS IN OPEN CIRCUIT VOLTAGE (OCV)

Figure VI-3

A gradual volt-amp curve is desirable for out of position welding. In surface applications, minimum control of the weld puddle can be controlled by electrode manipulation and adjustment of the arc length. However, for most underwater welding a constant arc length is used, and manipulation of the electrode is limited. A steeper volt-amp curve is desirable for underwater welding since variations in the current are reduced and a higher OCV is utilized. A higher OCV increases the ability to initiate an arc underwater.

Another factor related to the stability of the arc underwater is the amount of inductance inherent or designed into the power supply. Inductance determines the lapse in time between arc length (voltage) and current variations, the greater the inductance the more sluggish the response time. With inverter type power supplies the inductance is typically very small and changes in current are nearly instantaneous. Rapid changes in the current produce unstable arc characteristics and decrease the ability to manipulate the electrode. Electronic inductance boards or coiling the welding lead around a section of iron or ferritic pipe have been successful in increasing the inductance and stabilizing the arc for underwater applications.

Recent developments have shown that a power supply capable of delivering pulsed power can provide additional arc stability, spatter control and greater control of penetration, especially for out of position welding. As stated above, manipulation of the electrode is usually limited for underwater welding, and controlling the weld puddle for out of position welds is difficult. Pulsed current produces effects similar to those observed when manipulating the electrode with a gradual volt-amp curve. By regulating the duration and level of the peak and background current pulses, the molten pool and transfer of molten droplets can be controlled. When the pulsing rate corresponds to the droplet transfer rate, the stability of the average current improves, consistency of the weld bead is increased and short circuiting is reduced or eliminated. A pulsing rate of approximately 80 to 90 pulses per min. with 35% duration emphasized on the peak current has been proven effective for underwater SMAW. The shape of the pulse or wave form, such as sine, square, etc. are presently being studied to determine their effects on arc stability.

Inverters

The inverter type power supplies have an advantage of being more compact and energy efficient than transformer rectifier type power supplies. The inverter has a more controllable and smoother DC output which reacts faster to variations in arc length, keeping a true constant current. The inserter being lighter and smaller in size allows a high-strength plastic to be used to encase the power supply. The plastic case does not conduct electricity and reduces electrical hazards. Pulsed current and slope control are common on the inverters, to help stabilize the arc and control the weld puddle. As stated above, the power supply can be modified with an inductor or stabilizer to increase the amount of inductance.

The inverter type power supply immediately rectifies, with a series of capacitors, the primary AC input to DC. DC current is then switched off and on (inverted) very rapidly using silicon controlled rectifiers (SCRs) or thyristors, resulting in a high-frequency AC output between 5 and 30 kilohertz (Khz). A transformer steps down the high-frequency AC voltage to a weldable range which is rectified to DC for welding. The output of an inverter is controlled by varying the frequency of the AC (switching rate of SCRs). The inverter type power supplies are smaller and lighter than comparable conventional units, since only a small transformer is used to step down the high frequency AC voltage. The transformer can be reduced from 200 lb to only 12 lb for a 300 amp welding power supply.

Transformer Rectifiers

The normal transformer rectifier type welding power supply initially steps down the high-voltage, AC input to a weldable range. A large and considerably heavy transformer is needed to step down the normal 60 Hz AC input. Diodes, SCRs, thyristors or power transistors are then used to rectify the current to DC for welding. The transformer rectifier is controlled by regulating the current through the transformer, by means of a saturable reactor, electronic switching, or by regulating the turns or resistance in the secondary. The size and weight of a transformer rectifier power supply is directly related to its current carrying capacity. Due to the size and weight, a substantial frame and cover are needed to protect the power supply.

Motor Generators

The generator of the motor generator power supply is rotated by either an electric motor, or a fuel powered internal combustion engine. The motor or engine turns a rotor armature system within sets of stationary magnetic field coils, producing an AC current through the armature. A commutator picks up half cycles of the AC through contact brushes mounted around the armature, producing a DC output. The commutator can best be described as a mechanical rectifier. The output is adjusted with a rheostat which can vary the current through a usable range.

Another more modern design of a motor generator power supply uses a rotating field and generates three-phase AC current which is rectified and controlled through a series of diodes or SCRs. This type of motor generator power supply is able to supply both CC and CV welding current to support multi-process use. This is accomplished through electronic control of the rectification circuits.

Both designs offer superior arc stabilization resulting from the inability of the rotating assemblies to quickly respond to changing events, such as arc length. A fuel driven motor generator welder should be used only when sufficient ventilation is present, preferably outdoors.

General Equipment

Underwater SMAW requires essentially the same equipment as used in normal surface welding. Although, special precautions are needed to assure the safe use of the equipment underwater. The equipment needed to set-up a complete welding circuit will be discussed in this section.

Cables and Connections

The ground cable and welding leads are normally made from 2/0 size cable, for underwater welding. A 3/0 or 4/0 cable size are utilized, to reduce the voltage drop, if welding is done at extreme depths. Figure 3-2 illustrates voltage drop as a function of cable length and size. Since the welding lead is a fairly heavy cable, a short 1/0 cable, called a "whip lead," is usually connected to the end of the welding lead. The "whip lead" will reduce fatigue caused by the heavier weld lead and increase the ease at which the electrode holder is manipulated.

Cable recommendations for underwater welding applications include:

- Cables should be "extra flexible" (neoprene) for improved maneuverability and to reduce the chance of tearing.

- Cables should also be fully insulated the entire length including all connections. Wrapping connections with rubber or plastic tape is recommended to reduce the potential for inadvertent arc strikes and adverse effects of electrolysis.

- Cables should be as short as possible to reduce voltage drop.

- Ground and welding leads should be of the same current carrying capacity.

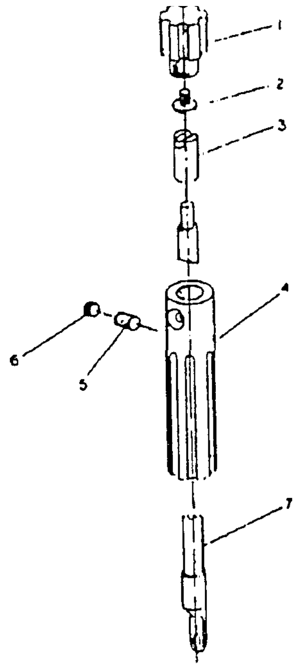
Use of appropriate cable sizes and insulation will reduce voltage drops and current leakage, which reduces corrosion caused by electrolysis and the need for a higher output from the power supply. Ideally, when not in use, cables should be rinsed, dried and stored in a dry, oil and grease free environment, to reduce the possibility of insulation breakdown.

Safety Switch

A safety switch between the electrode holder and the power supply or other device which fully disengages the current supply to the electrode holder is required. This set-up allows the dive tender or weld supervisor to quickly connect or disconnect the welding current. A single pole single throw knife switch is normally utilized. The safety switch should be rated for no less than the maximum output of the power supply. For further safety a "dead-man" switch on the electrode holder can be utilized to initiate and disengage current.

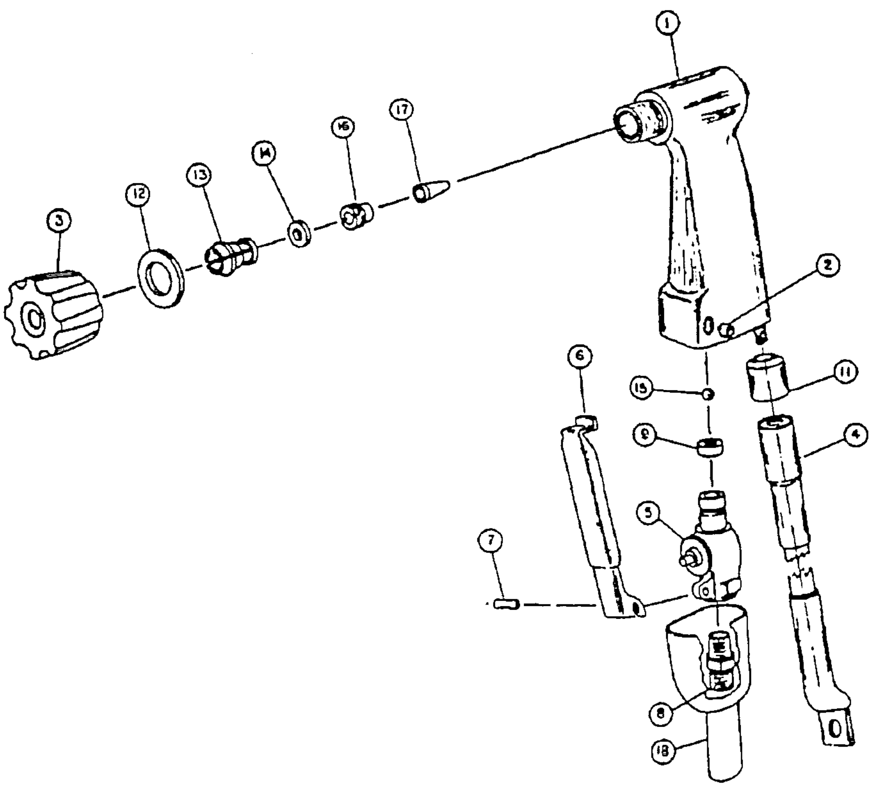
Electrode Holder

The electrode holder is designed specifically for underwater welding. All metal current carrying parts are fully insulated and sealed. The electrode holder design permits easy removal and replacement of electrodes, is highly durable and light weight. A typical underwater electrode holder (torch) utilizes a counterclockwise rotation to open the electrode holding mechanism, called the collet or head, and a clockwise rotation clamps the electrode in place. The circuit should always be open (current off) when changing electrodes, even with completely insulated equipment and electrodes. Some underwater torches are designed for both cutting and welding while others are single purpose, used for only for welding, as shown in Figures VI-4a and VI-4b.



1 Head
2 Cap
3 Body
4 Handle
5 Set Screw
6 Plug
7 Cable Assembly

UNDERWATER WELDING ELECTRODE HOLDER
Figure VI-4a

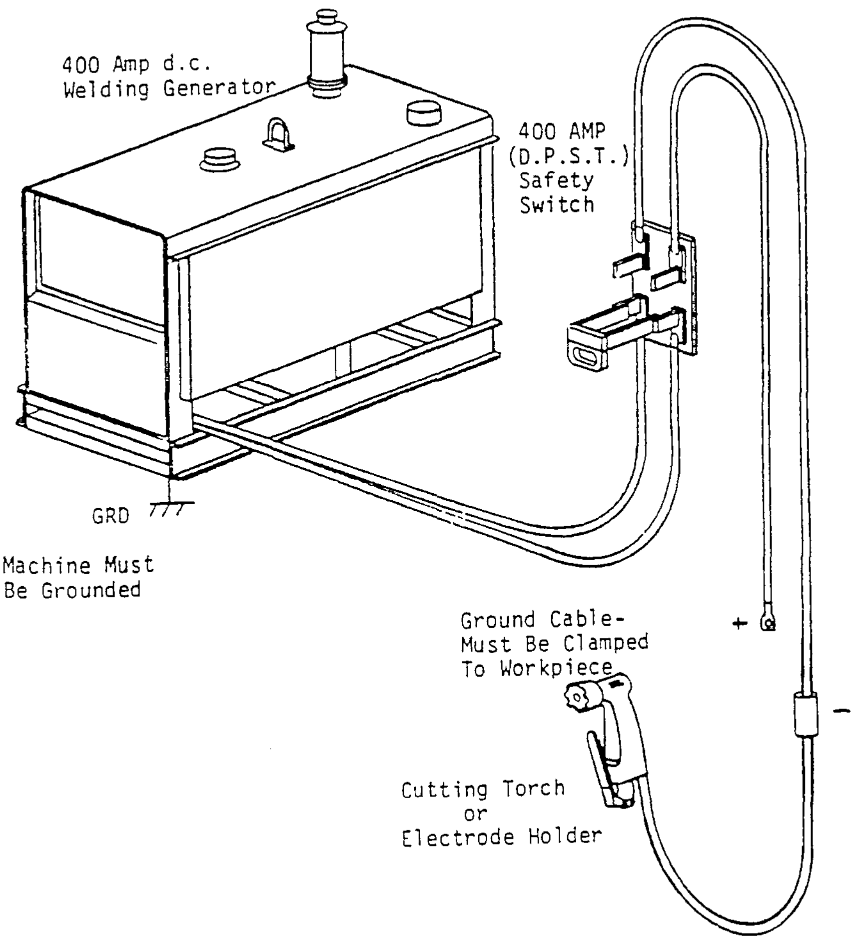


1	Sea Torch Handle
2	Set Screw (2 req'd)
3	Molded Collet Ring Ass'y
4	Cable Ass'y
	Oxygen Valve/Lever Ass'y
5	Oxygen Valve
6	Valve Lever Ass'y
7	Pin
8	Adaptor
9	Washer
11	Cable Tip Insulator
12	Washer
13	1/8" Collet Chuck*
	5/32" Collet Chuck*
	3/16" Collet Chuck*
	5/16" Collet Chuck
	3/8" Collet Chuck
14	Washer
15	Ball Check Valve
16	Blowback Retainer
17	Spark Arrestor
18	Valve Boot

COMBINATION CUTTING & WELDING TORCH
Figure VI-4b

Ground Clamp

The ground clamp or connection must be able to be securely fastened to the work and be able to carry the maximum current capacity of the power supply. The ground clamp should have a large contact surface area. A C-clamp or similar assembly is ideal and is typically used for this purpose.



GENERAL SET-UP FOR UNDERWATER ARC CUTTING AND WELDING
Figure VI-5

Equipment Set-up

The first step for assuring a safe environment for underwater welding is the equipment set-up. The general set-up for underwater welding is regulated to a greater extent than normal surface welding applications (Figure VI-5). Precautionary measures must be observed to assure the safety of the diver/welder. To establish a safe work environment the following recommendations are usually implemented:

- The power supply is isolated from the work area by an insulated platform. This is achieved by placing a wooden platform or rubber mat under the power supply.

- The frame of the power supply is grounded to an appropriate earth ground.

- Connections are clean and securely fastened. Fastening is achieved by either brazing or bolting the connections, followed by wrapping with a rubber or plastic tape to fully insulate the connection. This reduces the voltage drop as well as decreases the potential for electric shock.

- The ground cable or connection is securely fastened to the work with a metal to metal connection.

- The ground clamp is positioned as close to the work as possible and moved after each weld if necessary.

- All cables including welding leads, ground cable, umbilical cord, pneumatic and water lines, and communication lines are routed away from the work area, so they do not hindering work proceedings.

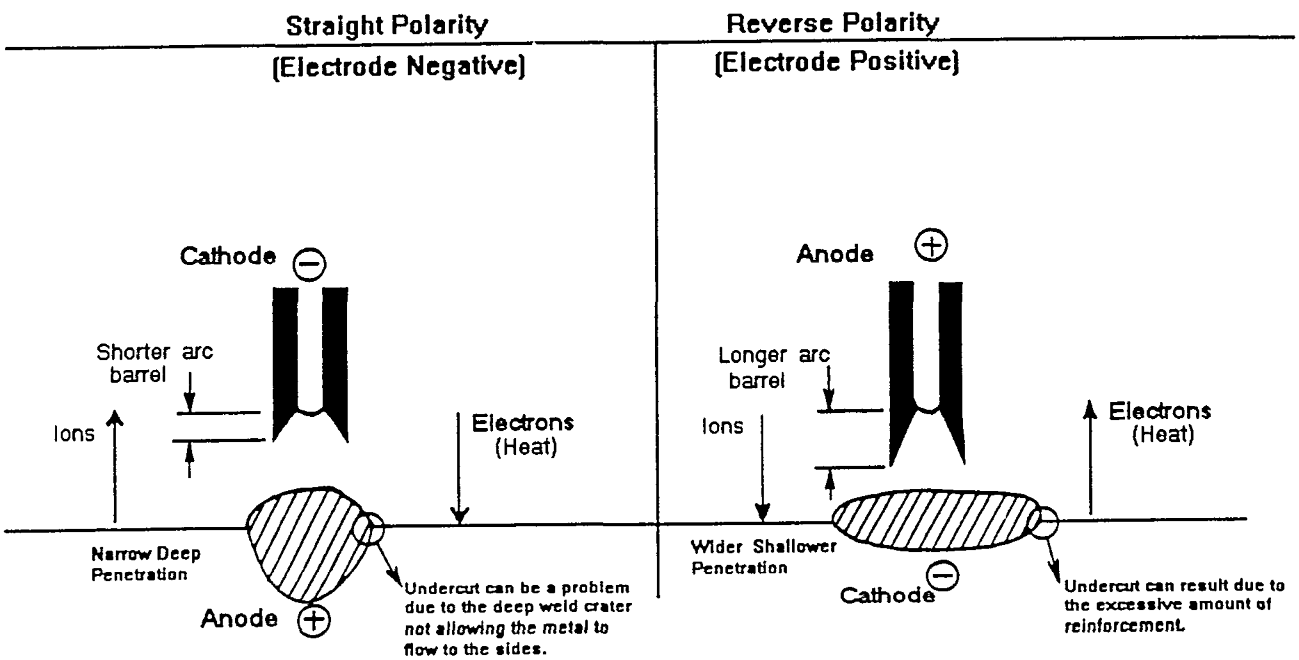
- All slack is removed from the cables to eliminate possibility of cutting or damaging the cables or umbilical cords, during operations.

Techniques

Polarity

For underwater SMAW direct current (DC) straight polarity (electrode negative) is normally used over DC reverse polarity (electrode positive). Although both polarities have been utilized in the underwater environment, each should be evaluated under the specific individual circumstances for the particular application and electrode selection. AC and DC reverse polarity cause electrolysis of the metal parts in the welding torch and cable connections and exhibit increased deterioration of these current carrying components.

The welding current polarity also affects weld bead characteristics, such as penetration, bead width and spatter. As seen in Figure VI-6, reverse polarity will produce an increase in the bead width to penetration ratio, compared to straight polarity. With reverse polarity the heat is directed toward the electrode, increasing the consumption (melting rate) of the electrode core and producing a larger extension of the unmelted flux sheath. The increased melting rate may cause undercut. With straight polarity, the melting rate decreases and more heat is distributed toward the base plate. The decreased melting rate may not allow molten material to flow into the toes of the weld, also causing undercut. Approximately 80% of the heat input is directed toward the anode (+), 5% is directed toward the cathode (-) and 15% is dissipated away through the water and gas bubbles (12). Figure VI-6 illustrates variations in heat input as related to the polarity of the welding circuit.

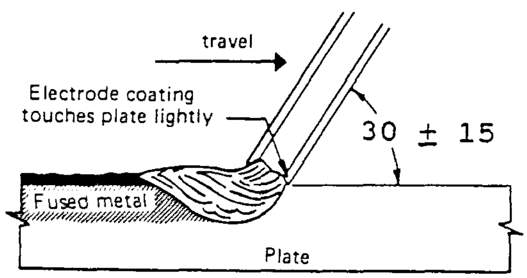


THE EFFECT OF ELECTRODE POLARITY ON WELD BEAD CHARACTERISTICS
Figure VI-6

Electrode Manipulation

Two basic techniques are used for the manipulation of the welding electrode, one being a "self consuming" or drag method and the other being a weaving or oscillating method. Both techniques pull the electrode in the same direction as the travel. Actual electrode manipulation will vary due to the skill level of the diver/welder, fit-up, and the joint configuration.

In the "self consuming" (drag) method, the electrode is pulled (dragged) across the surface of the material with a slight pressure on the electrode, maintaining constant contact with the material, as seen in Figure VI-7. The flux sheath of the electrode is actually submerged in the weld puddle, as the electrode is advanced along the length of the weld. The flux sheath is designed to burn away slower than the electrode core so that the unconsumed flux can be utilized as a guide to maintain a constant arc gap and to shield the arc from the water. A constant arc gap is critical for maintaining consistent amperage and voltage characteristics and uniform bead appearance. Short arc gaps promote lower arc voltage and short circuiting while longer arc gaps produce an unstable arc, increased spatter and a decrease in the efficiency of the shielding gas or bubbles.



"SELF CONSUMING" OR DRAG TECHNIQUE
Figure VI-7

The "self consuming" method is always used for root passes since a narrow consistent bead width, with increased penetration over the weave technique is produced. The skill level required is lower with this technique because a consistent gap between the electrode and the work material does not have to be maintained by the diver/welder. The "self consuming" method will typically produce an equal legged fillet weld with a leg length similar to the diameter of the electrode. For the "self consuming" method a groove or guide will improve the ability of the diver/welder to follow a weld joint.

Fit-up and Position

Poor fit-up caused by distorted or bent components and excessive gaps at the root may require the oscillating technique of electrode manipulation. A higher skill level is needed to manually control the arc length while oscillating, although poor fit-up and improper joint configuration cannot always be compensated for by the diver/welder. Fillet welds permit the electrode to be manipulated along the corner of the joint and is an ideal joint for underwater welding for this reason.

Out-of-position welding requires a more consistent travel speed and arc gap, and a diver/welder with greater welding capabilities. When welding in the vertical position, it is recommended that travel is in the downhill direction, using the "self consuming" method of manipulation. Vertical-up welding is not recommended because of slag entrapment and poor visibility caused by the dynamic bubbles generated by the arc. Vertical-up welding can be utilized with an oscillating technique if the joint fit-up is not appropriate for downhill welding. Vertical up welding requires a greater skill level since arc length needs to be maintained manually by the diver/welder. Welding in the overhead position requires a narrow range of welding parameters and further increases the difficulty of the weld.

The most important variables that govern the performance of underwater SMAW welding are the welding parameters, joint preparation, electrode selection, and water-proofing technique. The welding parameter envelope is normally limited for underwater welding. To produce the ideal weld bead, with respect to penetration, bead width, and appearance, the voltage, amperage, and travel speed, etc., need to be rigidly controlled.

Work Angle

The work angle or lead angle is the angle between the work piece and the electrode measured in the direction of travel. The work angle for underwater SMAW will vary with diver/welder. An angle of approximately 30° is recommended, although plus or minus 15° is acceptable depending on diver/welder preference (Figure VI-7). Excessive undercut may indicate use of an incorrect work angle. The work angle determines the size of the arc column and the current density. A low-work angle will increase the size of the arc column while decreasing the current density which results in a reduction in penetration and increased bead width.

Arc Length

The arc length or gap is self regulating when the electrode is manipulated using the "self consuming" method, described above. An underwater arc length is typically 1/2 the diameter of the electrode. A typical arc length for in-air welding ranges from 1/2 to 1 times the electrode diameter. Constriction of the arc is also observed as water depth increases.

Travel Speed

Travel speed is influenced by both the electrode type and current and is typically slower than in-surface welding. Using the "self consuming" method the travel rate is regulated by the ability of the weld puddle to fill the crater formed by the arc. The natural rate of consumption per individual electrode should be evaluated through practice and mock-up training. Differences in the flux chemistry will vary the natural rate of consumption. Travel speed affects the bead width, penetration and consistency. An attempt to travel too quickly will produce a narrow inconsistent weld bead with narrow bead width and low penetration. Too low of travel speed will produce a wide bead with excessive build up. Incorrect travel speed will cause undercut due to the excessive or insufficient reinforcement produced.

Amperage and Voltage

SMAW requires a constant current power supply with a conventional volt-amp curve, as seen in Figure VI-2. A steep volt amp curve limits the variations in the welding current associated with fluctuations in the arc length. A constant potential (voltage) power supply is not practical for manual SMAW operations and should not be used. Welding current for SMAW is basically controlled by setting the current level on the power supply. The arc voltage also affects the current output, but to a smaller extent. The arc voltage, on the other hand, is a function of the arc length and the electrode type. The current-voltage relationship is best described using a volt-amp curve, as shown in Figure VI-3. As illustrated in the volt-amp curve, the slope of the curve determines the relationship between voltage and the current output. An increase in the arc length boosts the arc voltage and decreases the current, and vice versa.

Open circuit voltage is a function of the welding power supply and is not related to the arc voltage during welding. Open circuit voltage (OCV) is the voltage present prior to the initiation of the arc and the welding load. For underwater welding, the arc is more difficult to initiate and a higher open circuit voltage or "arc start control" option may be desired (See section on SMAW power supplies).

For underwater SMAW, the current setting is influenced by the electrode type and size, and position of welding, just as in surface welding. The current needed to weld underwater is usually greater than in surface operations. An additional 20 to 25% increase in required current is the general rule of thumb for underwater welding. Figure VI-8 provides a general starting point for selecting the appropriate current settings in relation to electrode size, material and welding position. Each application requires evaluation of the welding variables during mock-up training and welding procedure qualifications plus confirmation of the variables with a test (confirmation) weld prior to each general operation.

UNDERWATER WET SHIELDED METAL ARC WELDING PARAMETERS

Figure VI-8

Diameter		**Material**	**Current Settings (Amps)**			
Inch	**MM**		**Fiat**	**Horizontal**	**Vertical**	**Overhead**
1/8	3.20	Mild Steel	160-170	150-170	140-165	140-160
6/32	3.97	Mild Steel	180-210	170-210	170-210	170-190
3/16	4.76	Mild Steel	250-280	240-280	240-280	235 -275
3/32	2.38	Stainless Steel	115-125	115-125	115-125	115-125
1/8	3.20	Stainless Steel	135-150	130-150	125-145	125 -145
6/32	3.97	Stainless Steel	150-200	140-200	140-190	140-180
3/16	4.76	Stainless Steel	175-250	165-250	165-240	165-235

Note: The amperage values are averages and sample welds should be made and inspected to adjust the settings for specific conditions.

Sequence of Operation

The diver/welder must clean the weld joint area prior to welding and remove all slag or other debris between passes. Trapped slag and impurities are detrimental to the mechanical properties of the weldment. All paint, rust, grease and marine growth should also be removed prior to welding. Cleaning can be done with a wire brush and a pneumatic or water driven chipper or grinder. The stability of the arc during welding is severely affected by the surface condition and cleanliness of the work area.

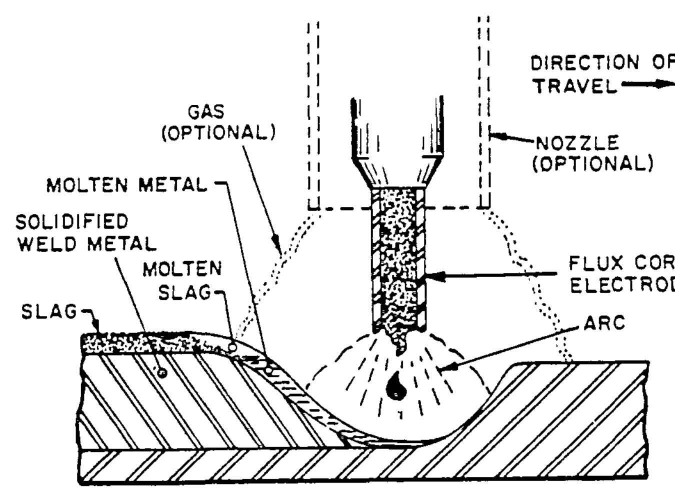
With the welding power supply disengaged (current off), the diver/welder positions himself in a manner so that he can perform the weld. After the diver/welder is positioned, the electrode tip should be scratched or tapped against the metal to clear the waterproof coating from the tip of the electrode. With the electrode in position to start the weld, the diver/welder should instruct the dive tender or dive supervisor to supply power to the welding circuit. A "dead-man" switch on the electrode holder may also be used to engage and disengage power. The diver/welder should replace or remove the electrode while the safety switch is in the "CURRENT OFF" position. In addition, electrodes should not be placed in the holder, while the diver is in transient. Electrodes can be lowered to the diver as needed, to reduce the time the electrodes are exposed to water. Waterproof coatings may deteriorate with extended exposure allowing water to absorb into the flux. Waterproof coatings are discussed in the Materials section.

In addition, the diver/welder should never be in direct contact with the grounded work or position the electrode holder so as to point the electrode in the direction of himself or other divers. The diver/welder should always position himself so that he is facing the ground connection. By turning his back to the ground connection, the diver/welder may make himself part of the electric circuit. At the completion of the weld the diver/welder should instruct that the power to the welding circuit be disengaged. The dive tender should always confirm the instructions of the diver/welder. Communications should be maintained throughout the entire sequence. Communications and diving safety are discussed in Chapter 1.

Underwater FCAW

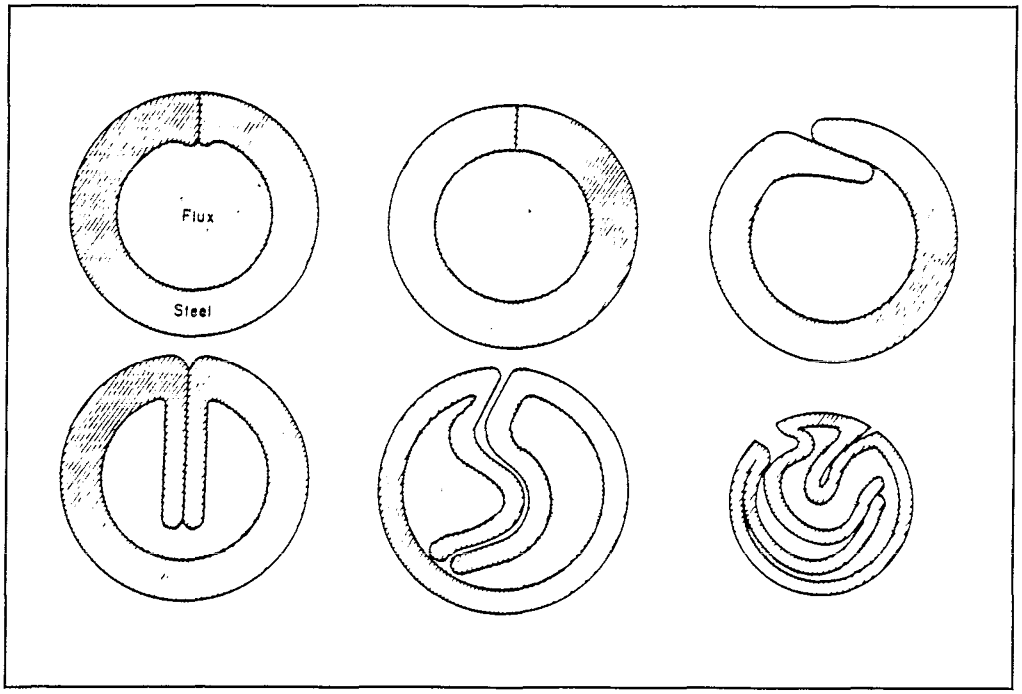
Principles

The flux-cored arc welding process (FCAW) typically uses the same equipment as the gas metal arc welding process (GMAW). The main difference between these processes is the welding wire. GMAW uses a solid wire while FCAW uses a metal sheath filled with flux and/or alloying components, as seen in Figure VI-9.



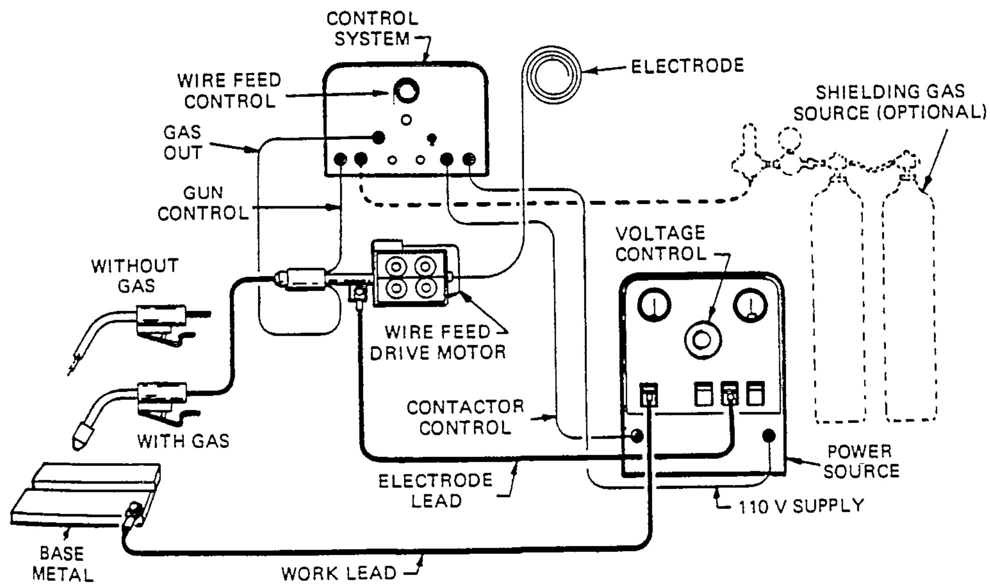
FLUX-CORED ARC WELDING PROCESS
Figure VI-9

FCAW, as well as GMAW, utilizes a continuously fed consumable welding wire to maintain an arc and act as a filler material. FCAW is utilized for out of position and higher deposition welding in normal circumstances, which makes it a prime candidate for underwater welding. FCAW can be used as a semi-automatic process and is easily adapted to automatic or machine welding and is ideal for internal repair applications restricted to divers. Welding wires designated for FCAW, can be designed as a self shielded or gas shielded process. A self-shielded or "open arc" welding wire forms its own shielding gas and slag, which closely simulates SMAW underwater. A gas shielded welding wire employs an additional gas shielding to protect the molten transfer and weld puddle. Examples of typical welding wires for FCAW are shown in Figure VI-10. The basic principles of FCAW are described below.



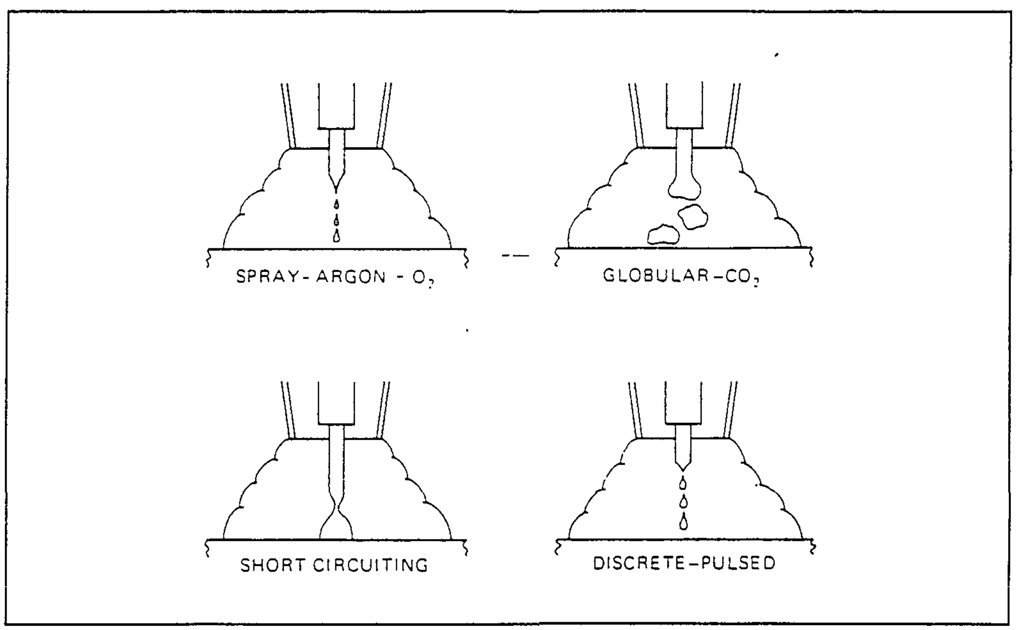
TYPICAL FLUX-CORED ELECTRODES DESIGNS
Figure VI-10

The welding wire is fed from a coil, through a liner to the welding gun or torch. A separate unit, called the wire feeder is used in conjunction with the power supply to supply the wire to the welding gun, as seen in Figure VI-11. Current is introduced to the welding wire at the end of the welding gun by means of a contact tip. The welding wire passes through the contact tip picking up the welding current. The arc is initiated when the wire contacts the work and is maintained by the continuously fed wire. The heat of the arc produces a molten puddle and melts the welding wire as it enters the arc. The molten metal is transferred across the arc in the form of droplets, which coalesce with the molten base metal to form the weld metal. The molten materials are protected by the gas formed from the decomposing flux and the slag solidifying on the weld metal.



TYPICAL FLUX-CORED ARC WELDING SET-UP
Figure VI-11

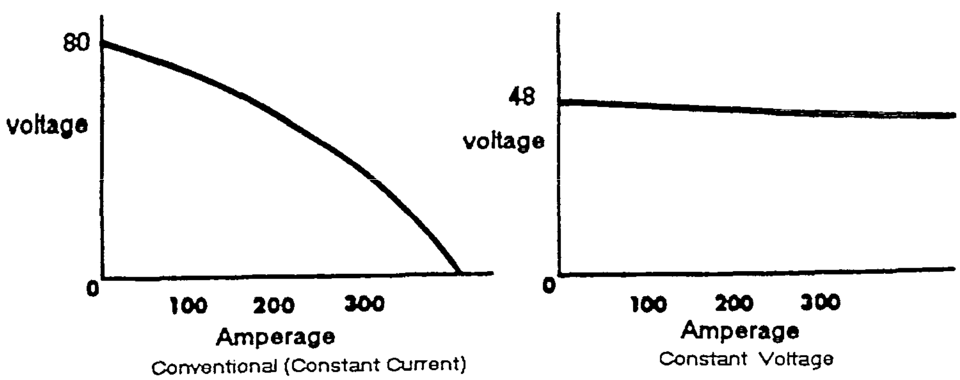
The manner in which the molten droplets are transferred across the arc is referred to as the transfer mode. Transfer modes shown in Figure VI-12 are determined by the volt-ampere characteristics, wire size and composition, and shielding gas being employed. The transfer mode for underwater applications is limited primarily to a globular mode. Pulsed arc welding has been used to help stabilize the arc and globular transfer mode. As with the SMAW process, the degree to which the gas and slag can protect the molten transfer and weld puddle is affected by the wet environment.



METAL TRANSFER MODES FOR GMAW AND FCAW PROCESSES
UNDER DRY ATMOSPHERIC CONDITIONS
Figure VI-12

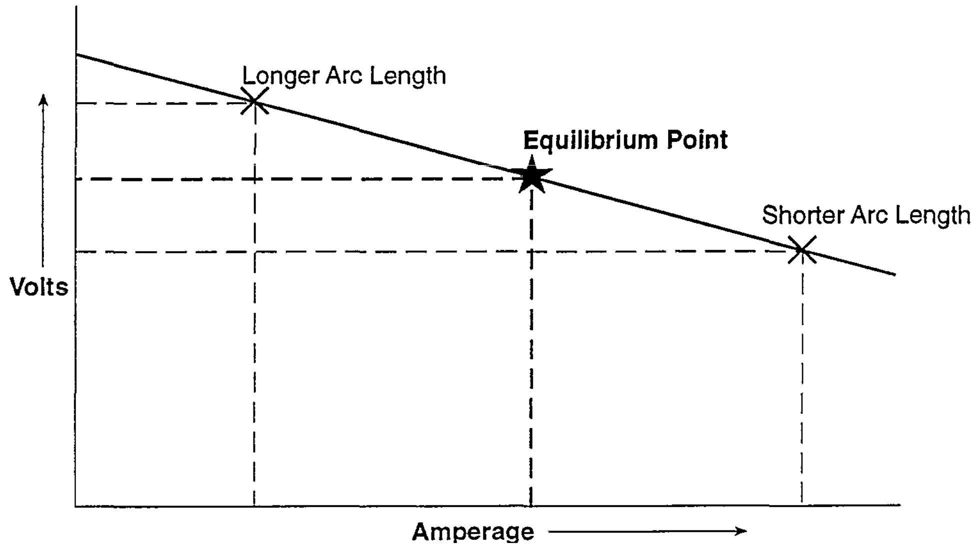
Power Supplies

A direct current power supply is needed for the FCAW process, with constant voltage (CV) or constant potential volt-ampere characteristics. A transformer rectifier or an inserter type power supply are commonly used, although some motor generators are utilized. Power supplies are described in section XX of the SMAW section. Constant potential refers to a very gradual volt-ampere output characteristic curve, compared to the steep curve utilized with CC power supplies. Figure VI-13 shows the variations in the Constant Current and Constant potential volt-amp characteristics. A CV power supply uses a wire feeder that controls and maintains a constant wire feed rate. The primary advantage of CV power supplies is the ability to self regulate the arc length and maintain consistent volt-amp characteristics, predetermined by the power supply design. The actual arc voltage depends on the volt-ampere slope control characteristics and the open circuit voltage (OCV) set on power supply. The welding current is typically controlled by varying the wire feed speed. Synergic CV power supplies have an inherent or preset arc voltage and pulse rate typical for various wire materials and wire diameters.



CONSTANT CURRENT (CONVENTIONAL) AND CONSTANT POTENTIAL (VOLTAGE) VOLT-AMPERE CURVES
Figure VI-13

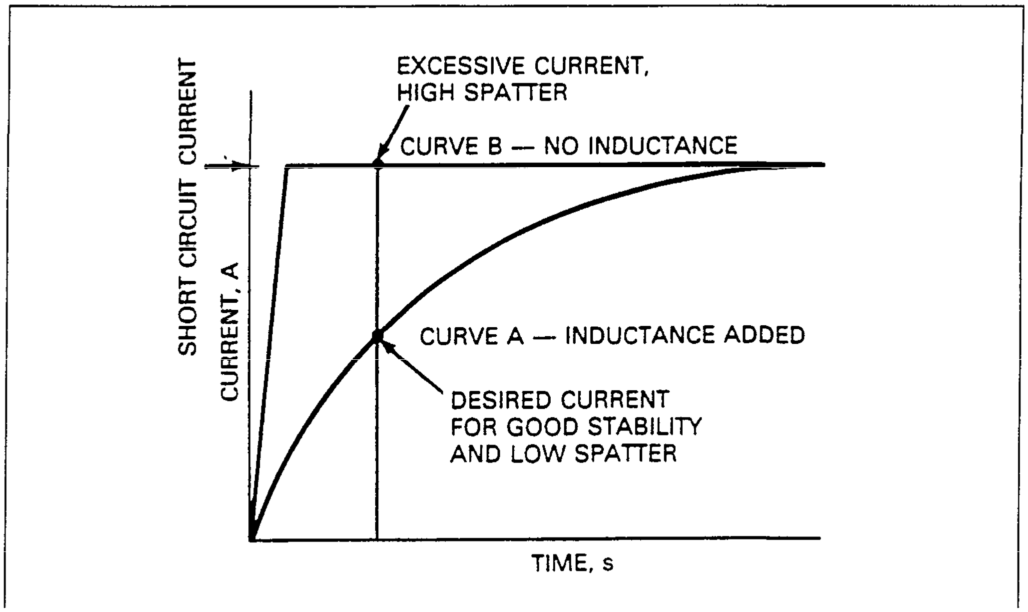
The principle behind the self-regulating arc characteristics are best described with a volt-ampere curve. In Figure VI-14, as the arc length is increased, current is decreased, reducing the melting rate. As the melting rate decreases, the arc length is forced to decrease back to its original or equilibrium point, since the wire feed rate is constant. A decreased arc length will produce a surge in the current, which increases the melting rate which automatically increases the arc length, to the equilibrium point. The slope of the volt-ampere characteristic curve determines the time in which the equilibrium point is reestablished. A greater slope will allow lower current surges and reduce the melting rate variation, allowing a smoother and quicker transition back to the equilibrium point. The optimum slope will produce a stabilized arc and increase the consistency of the bead appearance.



AUTOMATIC CONTROL OF CURRENT WITH CONSTANT VOLTAGE POWER SUPPLY
Figure VI-14

Pulsed power supplies have been utilized in the development of underwater FCAW to increase penetration, reduce the average current typically needed for underwater welding, and help control bead shape. A pulse rate corresponding to the rate of droplet transfer helps to stabilize the average current and reduces variations in the arc voltage. Maintaining a stable average current and arc voltage minimizes the fluctuation in the melting rate, stabilizes the arc, reduces spatter, and increases the consistency of the weld bead. This is especially noticeable in out-of-position welding.

The inductance of the power supply also affects arc stability. The amount of inductance controls the rate of response of the machine, which is important for underwater welding, as seen in Figure VI-15. Higher inductance forces the power supply via its volt-ampere characteristics to respond (adjust) slower, so that the arc is not extinguished in the process. Most CV power supplies provide sufficient internal inductance, although inverter type power supplies with their small transformer sizes may need additional inductance for proper operation underwater. Electronic inductors or stabilizers are generally available as optional equipment through the power supply manufacturer. Effects of inductance on current rise are shown in Figure VI-15.



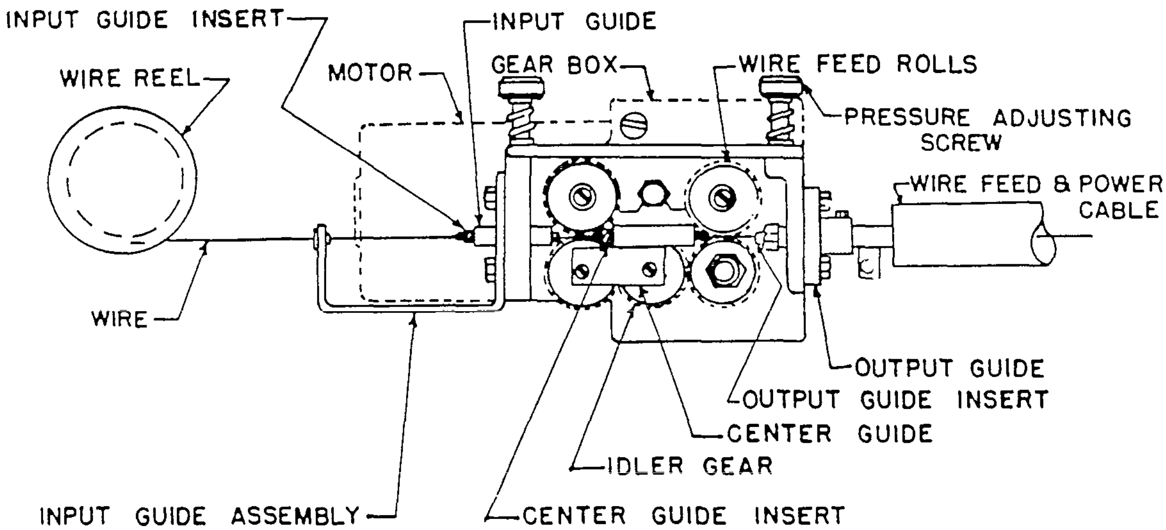
EFFECTS OF INDUCTANCE ON RESPONSE TIME OF CURRENT FLUCTUATIONS
Figure VI-15

General Equipment

(Figure VI-11). At this time, FCAW equipment is not manufactured or designed specifically for underwater wet welding applications. Commercial surface welding equipment has been modified to perform underwater. As with the wet SMAW equipment, safety is the first concern for the development of FCAW equipment for wet welding. The modifications on FCAW equipment are similar to the SMAW equipment, with a few exceptions related to the wire feeding mechanisms and safety interlocks on the welding circuit.

Wire Feeder, welding Lead and Gun

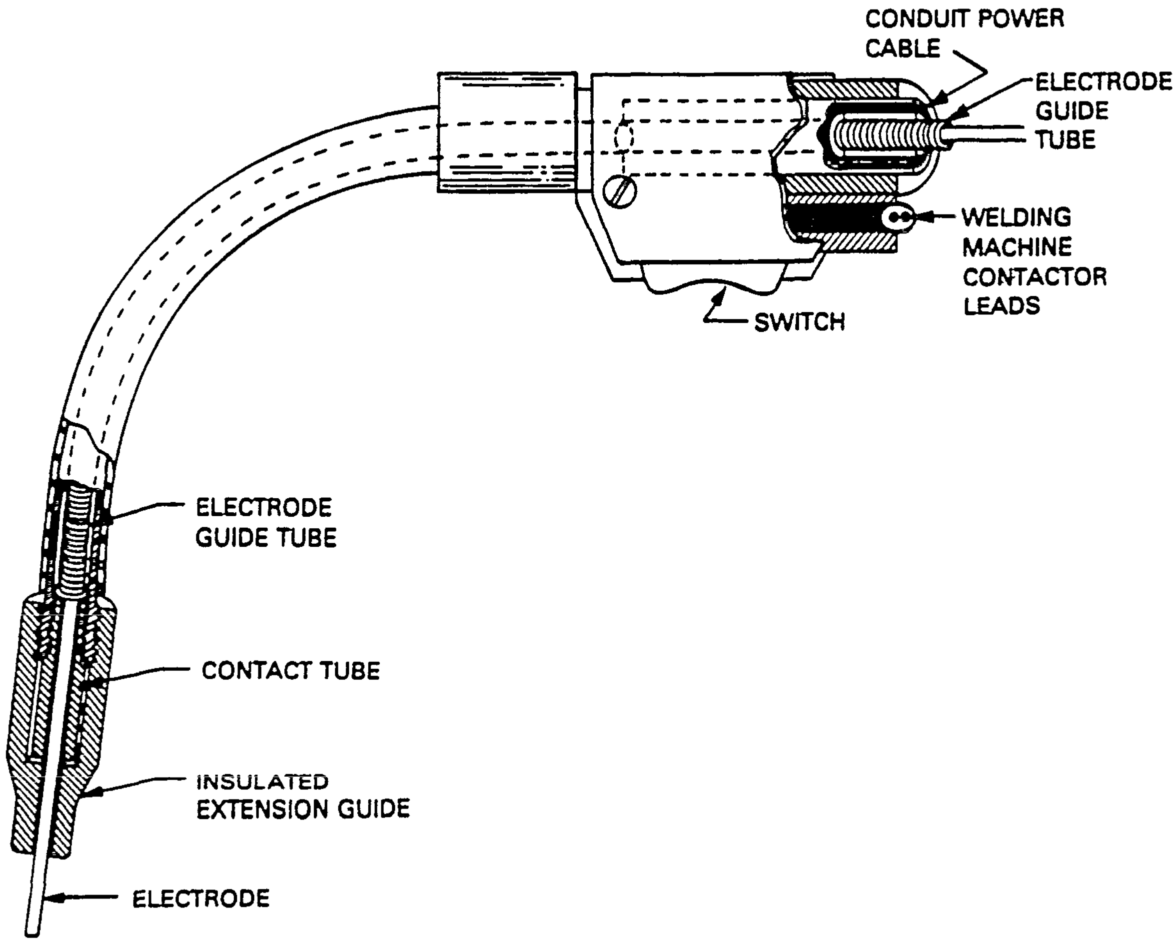
The wire feeder or spool gun equipment can be modified to be completely submerged or an extra long gun cable can used to reach a wire feeder on the surface. Submersible equipment is generally contained in a pressurized housing, sealed from the wet atmosphere, since it is important that the flux-cored wire remains dry prior to welding. The normal wire feeder unit consists of a electric motor, wire reel, wire feed rolls and wire guides which direct the wire into the liner or guide tube of the gun cable, as shown in Figure VI-16. The wire feed speed can be regulated at the wire feeder unit or remotely.



WIRE FEED ASSEMBLY FOR GMAW AND FCAW PROCESSES (HOBART)
Figure VI-16

The gun cable provides insulation for the power cable and the wire feed liner, which routes the welding wire to the welding gun. The gun cable can be made to accommodate any desired length, although the ability to feed welding wire greater than 25-30 ft distances without the use of in-line drives becomes difficult. The liner, in which the welding wire travels, should be made of a noncorrosive material such as teflon, stainless steel or nylon.

The welding gun guides the welding wire through a contact tip which energizes the wire, as shown in Figure VI-17. A trigger located on the welding gun initiates the wire feed and energizes the low-voltage control circuits that control the flow of welding current to the contact tip. The trigger also initiates the flow of shielding gas to the welding gun, although gas is not normally utilized in wet welding applications. The welding gun is also modified to electrically insulate the body and trigger of the gun from the diver/welder. A modified trigger is insulated within the welding gun and is designed to resist the pressures exerted by the water, so that the trigger is not engaged automatically.



WELDING GUN FOR SELF SHIELDED FCAW PROCESS
Figure VI-17

Safety Switch
As with an SMAW set-up, a safety switch between the work and the power supply is needed to disengage the current supplied to the welding wire. A similar set-up can be used with FCAW by inserting a switch between the power supply and the wire feeder. This set-up will permit the diver/welder to inch out the welding wire as needed without having current flowing to the wire. The safety switch should be rated for no less than the maximum output of the power supply. In addition, a "deadman" switch should be placed in the trigger circuit of the welding gun. A conventional trigger could become stuck or jammed in the closed position and present a safety hazard.

Cables and Ground Clamp

Cables used to supply the welding power to the wire feeder and ground clamp or connection must be properly sized for the welding current output of the power supply. The grounding assembly must be able to be securely fastened to the work and be able to carry the maximum current capacity of the power supply. Ground clamps, when used, should have large contact surface areas. A C-clamp is ideal and is typically used for this purpose.

Equipment Set-up

The typical set-up and safety considerations for underwater SMAW are used for underwater FCAW. The wire feeder unit can be separated from the power supply, although the greater the distance from the power supply the greater the voltage drop, as illustrated in Figure 3-2. The wire feeder unit restricts the mobility of the welding operation to within 20 or 30 ft of the wire feeder unless in-line drives are used to extend the working distance. For best access to the work area, the wire feeder unit should be placed directly above or slightly to the side of the work, so the gun cable is stretched to its full length. The cable must remain uninterrupted the entire length between the wire feeder and the welding gun. If the guide tube or welding wire becomes crimped or bent, it will backup in the wire feed rolls, or arc to the contact tip. If a submersible wire feeder or spool gun is used, the length of the welding gun cable can be kept to a minimum. The basic set-up for underwater FCAW is shown in Figure VI-11. Gas shielding is optional and has not proven to be viable for wet welding. The wire feeder, control system and wire reel are usually combined in one unit.

Techniques

As with underwater SMAW, the welding parameters are limited to a narrow range or envelope of amperage and voltage compared to dry, surface welds. To produce the optimum weld bead, these parameters must be rigidly maintained along with a consistent work angle, electrode stick-out length and travel speed. Optimal welding variables should be evaluated during mock-up training and welding procedure qualification.

Polarity

The effects of welding polarity are the same as described in the section above for the SMAW process. DC reverse polarity (DCRP) will produce a wide weld bead with shallow penetration while DC straight polarity (DCSP) produces a narrow bead with deep penetration. DCRP is commonly utilized for GMAW and FCAW, although both straight and reverse polarity have been found to produce acceptable bead appearances underwater. DCRP has the advantage of a greater melting rate, which will increase the deposition rate.

Electrode Position

The drag technique tends to produce the best results for underwater FCAW. When welding in the flat position, a drag angle or travel angle of 40 to 50° is used. For out-of-position welding, a drag angle of 45° tends to produce the best results. A work angle of 45° for fillet welds and 90° for groove welds has been found to produce optimum bead appearances. Deviations greater than plus or minus 5° generally have a significant effect on the appearance of the weld bead.

Stick out

Wire stick out is the distance between the work and the contact tip. The stick out length has been determined to be very critical in weld bead appearance and quality. Long stick out lengths increase the resistive heating of the wire, produce poor bead appearance, low penetration and unstable arc conditions. Shorter stick out produces excess spatter and problems maintaining a clean contact tip, due to the explosive weld puddles. A minimum stick out which maintains a clear distance from the weld puddle is desirable. For 1/16 and 3/32 in. diameter welding wires, stick outs of 3/8 in. and 1/2 in., respectively, are appropriate.

Travel Speed

Travel speed is also very critical to successful underwater FCAW welding. Too slow of a travel speed permits the molten pool to impinge on the arc, reducing penetration and producing a violent weld puddle. A slow travel speed also increases the bead width and produces excessive reinforcement which may produce undercut. With fast travel speeds, the arc tends to remain in front of the weld puddle, resulting in an insufficient weld deposit and undercut. The travel speed correlates to the electrode type and diameter, metal transfer mode, welding position and material being welded. Typical travel speeds for automatic and semi-automatic wet stainless steel FCAW are shown in Figure VI-18.

Amperage and Voltage

For GMAW and FCAW, the amperage is controlled by the rate at which the welding wire is fed into the welding arc. The constant voltage power supply automatically adjusts to the set arc voltage. Increased wire feed rates increase the amperage and a decrease in the wire feed rate decreases the amperage. The arc voltage which determines the arc length is controlled by the power supply. Typical electrical parameters are listed in Figure VI-18.

Where current pulsing is used, a pulse rate of approximately 120-136 pulses per second (pps) appears to provide good bead appearance and arc stability. Pulse durations are concentrated on the peak current at approximately 50 to 60%. Pulsing enables lower average amperage to be maintained, while sustaining a more stable arc with increased penetration.

UNDERWATER WET FLUX-CORED ARC WELDING PARAMETERS
Figure VI-18

I. Automatic Flux-Cored Arc Welding

			Kemppi PSS 5000 Settings						
Diameter	Avg. Amps	Avg. Volts	Pri. Time (msec)	Bkgrd. Time (msec)	Pri. Volts	Bkgrd. Volts	Pulse Rate (pps)	WFS (ipm)	TS (ipm)
1/16-in.	135-155	29-31	4.0	3.25	32	27-28	135	173-196	12
3/32-in.	225-250	27-29	4.0	3.25-4.0	32	28	125-135	134-160	12

II. Semi-Automatic Flux-Cored Arc Welding

			Miller Pulstar 450				
Diameter	Avg. Amps	Avg. Volts	Pri. Amps	Bkgrd. Volts	WFS (ipm)	Pulse Rate (pps)	TS (ipm)
1/16-in.	200	30	210	30	190	120	10-15

Note:
Filler Material: Weld-Mold 308L FC-0
Polarity: DCEN or DCEP
Lead Angle: 46 degrees
Stickout: 3/8-in. for 1/16-in. diameter wire
112-in. for 3/32-in. diameter wire

Other Wet Welding Processes

The versatility of wet welding has motivated the study of adapting welding processes other than SMAW to weld in wet environments. SMAW and FCAW processes, as discussed above, both provide slag and gaseous protection without external shielding. Other processes such as GMAW, SAW, GTAW and PAW, offer high-quality welds in dry atmosphere conditions, but the ability to use these processes underwater is complicated because the methods in which the weld puddle and metal transfer are protected from the wet atmosphere have been ineffective. The shielding gases and external flux used in these processes is difficult to introduce into the weld environment and also adds to the visibility problems associated with underwater welding. Resistance welding has also been attempted in shallow depths and in a controlled atmosphere but is not considered an acceptable practice for underwater repair applications at this time.

Only the GMAW and stud welding processes will be covered in this section. Other processes are not considered practical at this time and, therefore, are not within the context of this guideline.

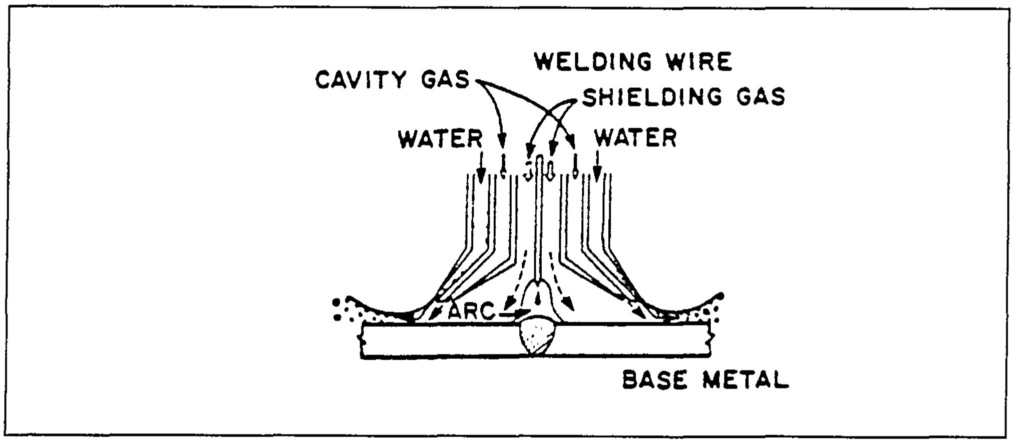
Underwater Gas Metal Arc Welding

GMAW for underwater welding was initially developed in the 1950s using portable chambers which displaced the water around the arc. In the late 1960s, submersible equipment was developed enabling underwater wet GMAW to be accomplished. Success with this process has been limited and has only been used in developmental research applications.

GMAW is characteristically the same welding process as FCAW with the exception of the welding wire and shielding methods utilized. As stated above, FCAW uses a hollow welding wire or sheath containing slag and gas forming elements, arc stabilizers and alloying elements while GMAW uses a solid welding wire which is solely protected by an external shielding gas. Both processes use continuous wire feed equipment with a constant voltage (CV) power supply to maintain a constant arc length. The welding wire or filler material doubles as the electrode. The equipment used for GMAW is identical to the equipment used with the FCAW process, as seen in Figure VI-11. Gas shielding is not considered an option and is a critical variable for GMAW.

Local displacement of the water around the arc has resulted in some success for the process without use of a dry chamber around the work area. At first, gas cups were modified to ensure a greater flow of shielding gas at higher pressures, in an attempt to force shielding gas to cover the weld puddle. This method created increased turbulence in the area of the arc, resulting in poor weld bead appearance, porosity, and diver visibility.

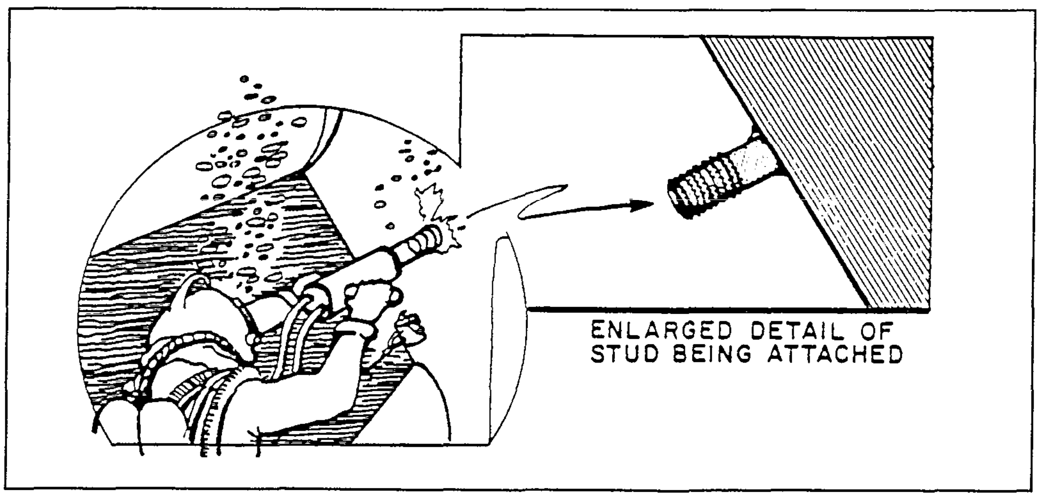
Another process being tested is the water jet method, developed in Japan, shown in Figure VI-19. This method uses a "water curtain" and gas flow to evacuate the water around the weld puddle and creating a pocket for the shielding gas. Cooling rates are significantly lowered and weld appearance is greatly improved using this method. Although visibility and manipulation of the welding gun is severely hindered.



LOCALLY DRY-WATER JET METHOD FOR UNDERWATER GMAW
Figure VI-19

Stud Arc Welding

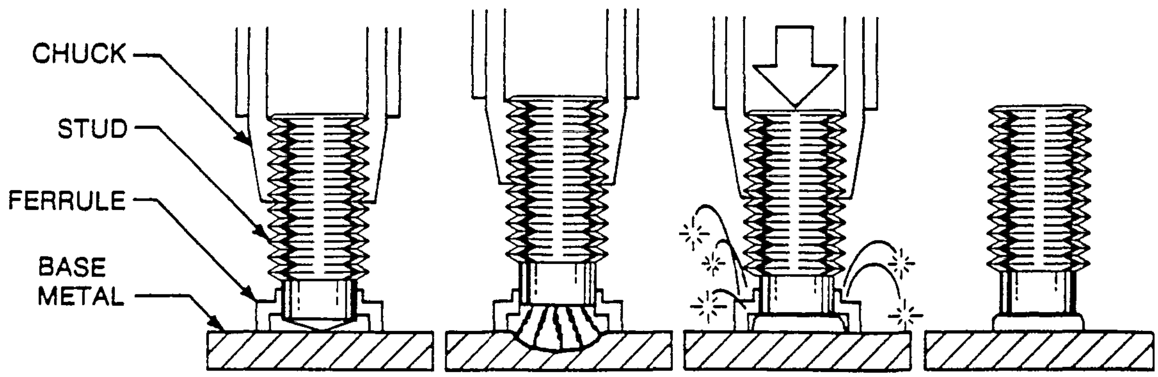
Like SMAW, stud welding has been used extensively in underwater construction and repair applications. Stud welding was first developed in the 1930s and by the 1940s slightly modified equipment was developed and tested for underwater applications, as shown in Figure VI-21. The stud welding process lends itself to underwater welding, since molten metal is not required to transfer across the arc, reducing the effects caused by the presence of water and the pressure exerted on the arc. However, the quenching effects of the water remains and needs to be considered for critical applications. Stud arc welding can be divided up into two categories, arc stud welding and capacitor discharge stud welding.



BASIC SET-UP FOR UNDERWATER STUD WELDING
Figure VI-20

Arc stud welding utilizes the heat created by the arc between the stud and the work to create a molten weld pool, similar to SMAW. The stud is then plunged into the molten puddle, with a constant pressure completing the weld sequence, as seen in Figure VI-21. Studs up to one inch in diameter have been successfully welded underwater with good metallurgical and mechanical results. Stud welding eliminates the need to drill and tap for connecting components, which may be detrimental to the mechanical properties of the base material and/or destroy water-tight conditions.

With the capacitor discharge method, an arc is generated by the rapid discharge of a bank of capacitors, which melts the base material. The stud is then plunged into the molten puddle, as with the arc stud welding method. The capacitor discharge method is rated for smaller diameter studs, usually 1/2 in. and less.



SEQUENCE FOR ARC STUD WELDING
Figure VI-21

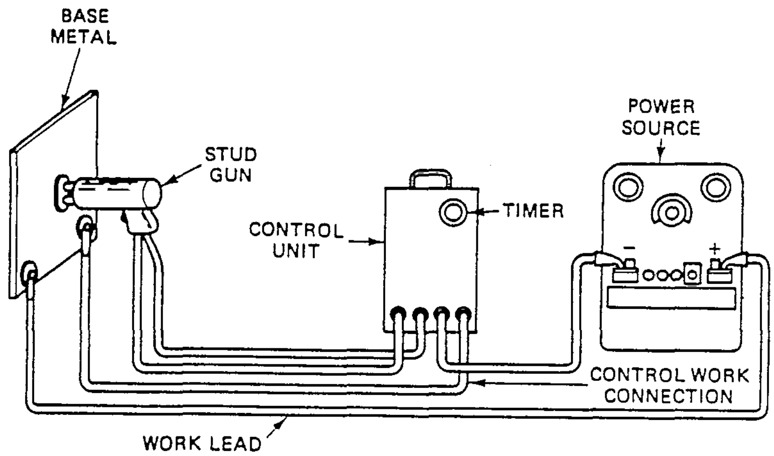
Equipment used for stud arc welding includes:

- Electric Output Controller
- Power Supply
- Stud Welding Gun

A D.C. power supply with constant current characteristics similar to SMAW power supply, is necessary for arc stud welding. Studs up to 0.5 in. diameter can be welded with the standard power supply. Studs greater than 0.6 in. in diameter require specially designed equipment, which can yield higher welding currents. Three basic power sources can be used; transformer-rectifier, motor generator, and batteries. Capacitor discharge stud welding only requires a power supply capable of charging the capacitors, typically 115V, 60 Hz.

An electric output controller is used to control durations in the welding sequence. The controller initiates and interrupts the welding current or capacitor discharge to control the molten puddle and metal discharged from the weld joint. The size of the stud determines the duration and amount of current necessary to complete a solid weld.

An underwater stud gun consists of a sealed and insulated body, a stud lifting mechanism, and a ferrule or ceramic cup holder. The welding lead and control cable are routed to the gun. The ground lead is attached to the work material. The weld set-up is very fundamental and is shown in Figure VI-22.



BASIC CIRCUIT DIAGRAM FOR STUD WELDING OPERATIONS
Figure VI-22

The stud lifting mechanism lifts the stud off the material once an arc is established allowing heat to build up without intimate contact. Once the puddle is established, the electric output controller interrupts the current and the stud is then forced into the molten weld puddle by the lifting mechanism.

The ferrule or ceramic cup is used to restrict the discharge of the molten material, center the heat of the arc and protect the molten material from oxidation. Figure VI-21 illustrates the function of a ferrule in the welding sequence.

Friction Stud Welding

Recent developments in friction stud welding equipment allow portable hand held applications to be performed both in air and underwater (Ramstud). As with stud arc welding processes molten material is not required to be transferred across an arc reducing the affects caused by the presence of water and the pressure exerted on the arc. Friction stud welding utilizes friction and pressure to produce coalescence between the stud and the work piece, without producing molten material. A rotating stud is brought into contact with the stationary work piece under an axial force. The heat created by the frictional contact produces a plastic zone at the faying surfaces. When the appropriate temperature is reached, an upsetting force is applied and rotation is stopped allowing the materials to be forge welded.

The advantages of friction stud welding include:

- Components are in intimate contact during the welding sequence.
- Molten material is not produced.
- Surface contaminates are forced from the faying surfaces during the welding process.
- Filler materials, shielding gases and fluxes are not required.

Equipment used for friction stud welding includes:

- Rotating and upsetting mechanism
- Controller unit
- Clamping system

As an example, the rotating and upsetting mechanism manufactured by Ramstud, is combined into a hand held unit which utilizes a 5 H.P motor and 100 psi. air supply. The clamping system can be magnetic, vacuum or mechanical. The Ramstud system is capable of welding studs from 5 to 16 mm (0.2 to 0.6 in.) diameter and 10 to 200 mm (0.4 to 7.9 in.) lengths. Friction stud welding can be used on austenitic stainless steels, nickel alloys, high strength materials, aluminum and titanium, as well as some non-metallic materials.

DRY CHAMBER WELDING

Dry chamber welding can be divided into two main categories: One, habitat chamber welding; and two, portable chamber welding. Habitat chambers are either constant pressure (one-atmosphere) or hyperbaric (ambient pressure) type chambers. Habitat chambers permit diver/welders to physically access the chambers, supporting direct contact with the work area and welding equipment. Some habitat chambers completely house the diver/welder, eliminating the need for diving equipment while others only permit the upper body or arm of the diver/welder to access the chamber. The advantages of habitat chambers include:

- The ability to produce code quality welds in a dry environment.
- Diver/Welder has direct contact with the work piece and does not require an increased skill level.
- Nearly all welding processes can be modified for use in habitat chambers.
- Greater depths and longer work periods can be addressed.

Habitat chambers have been advantageous for offshore pipeline and platform installation and repairs, plus ship repairs. Most repairs in nuclear facilities are usually in limited access locations at relatively shallow depths and the natural radiation barrier provided by the water is adequate, thus making habitat welding impractical and unnecessary. In addition, the cost and time related to designing and implementing a dry habitat chamber for individual weld repairs can be prohibitive.

Portable hyperbaric chambers or mini-habitats can be hand held or mounted to the local area of a repair. Welding equipment is mounted to the inside of the chamber and the diver/welder remains in the water, outside the chamber. The welding equipment is either manipulated through access holes or the entire chamber is manipulated. Completely automated welding equipment has been utilized in hyperbaric chambers in a few limited applications. Surface quality welds are possible with portable chambers, although, visibility and mobility of the process are significantly restricted. Portable chambers are usually limited to more fundamental welding processes where elaborate set-ups or precise joint fit-ups are not required.

Portable Welding Chambers

Hyperbaric welding is done at ambient pressure, consistent with the water pressure surrounding the chamber. The chamber is aligned either remotely or with the help of a diver, depending on the location of the repair application. Welding leads are routed to the chamber in the same fashion as the wet welding processes. All access ports are sealed and a gas mixture is generally used to displace the water from the chamber and also may act as a shielding gas for the welding process. Excess gases are vented off to eliminate pressure build up, which could break the chamber's seal with the work piece.

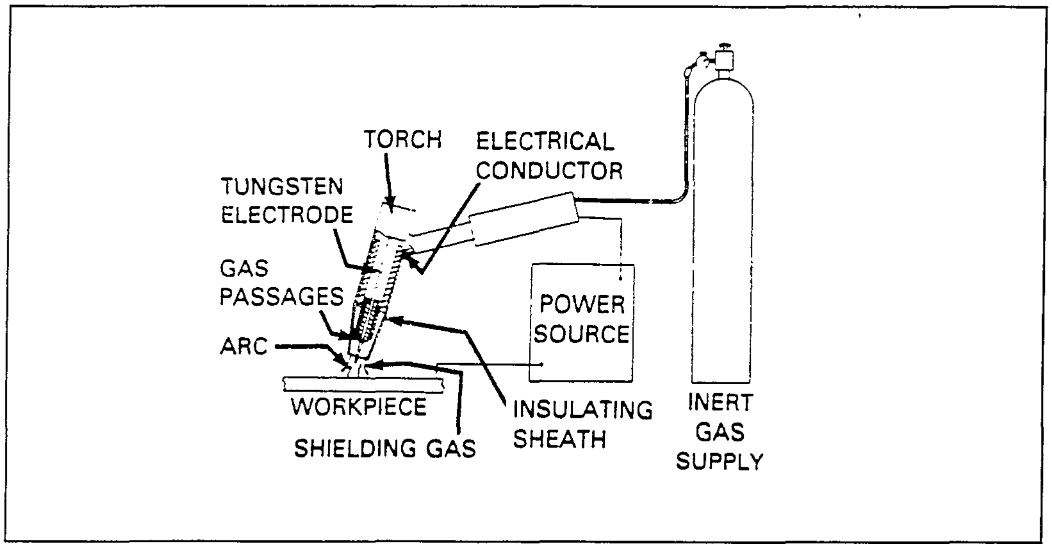
Chambers are usually made per application to ensure the fit-up corresponds closely to the geometry of the work piece.

Welding Processes

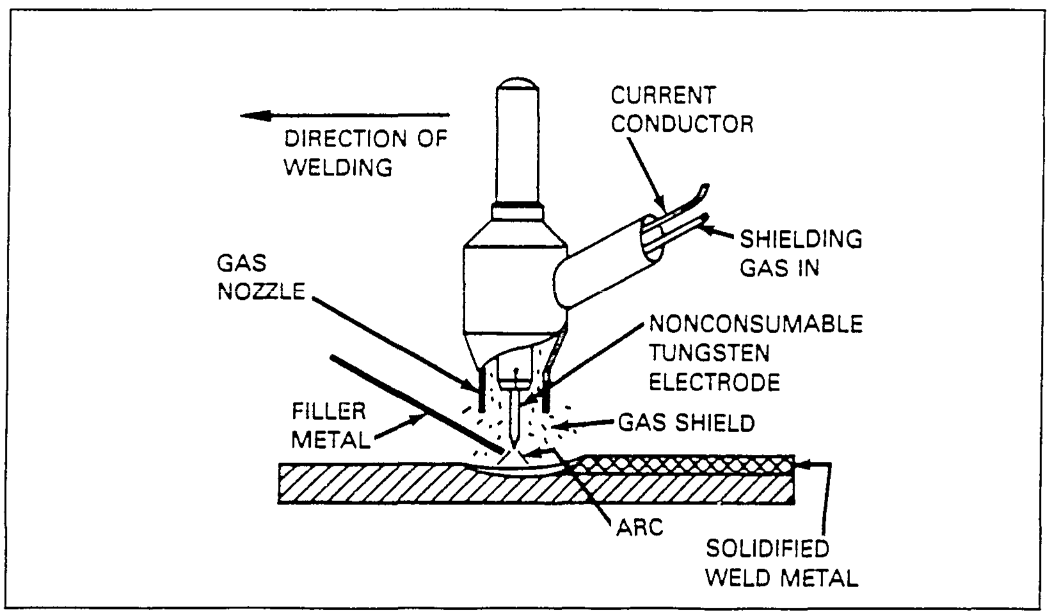
Gas tungsten arc welding (GTAW) and gas metal arc welding (GMAW) are predominately used for underwater chamber welding applications. GMAW and GTAW are both fundamental methods of welding, not requiring elaborate equipment set-ups. Both processes can be utilized as a semi-automatic or automatic welding process. Plasma arc welding (PAW) has also been developed for underwater applications but not extensively used at this time. SMAW is used in habitat chambers, although due to the difficulty in automating the process it is not preferred for smaller chamber applications.

GTAW

GTAW is easily modified for automated welding applications. A typical set-up for GTAW is shown in Figure VI-23. A constant current (pulsed current optional) power supply is used for GTAW, as described for underwater SMAW. A welding arc is produced by passing current between a nonconsumable tungsten electrode and the work piece. Filler material is fed into the weld puddle created by the arc as the welding torch is moved along the weld joint. Filler metal delivery equipment may be adapted to automatically feed into the weld puddle. The weld puddle and electrode are protected by a shielding gas which passes through a gas nozzle at the end of the welding torch and/or is directly pumped into the welding chamber. See Figure VI-24.



GENERAL SET-UP FOR GAS TUNGSTEN ARC WELDING PROCESS
Figure Vl-23



TYPICAL GTAW PROCESS
Figure Vl-24

The advantages of GTAW include

- Can be used autogeneously or with filler material
- Produces high-qualilty, defect-free welds.
- Uses conventional equipment and is easily automated.
- Capable of producing a root pass with increased penetration quality over other welding processes.
- Spatter free process
- Welding variables can be accurately controlled.
- The welding torch for GTAW can be modified to access most welding repair locations.

GMAW

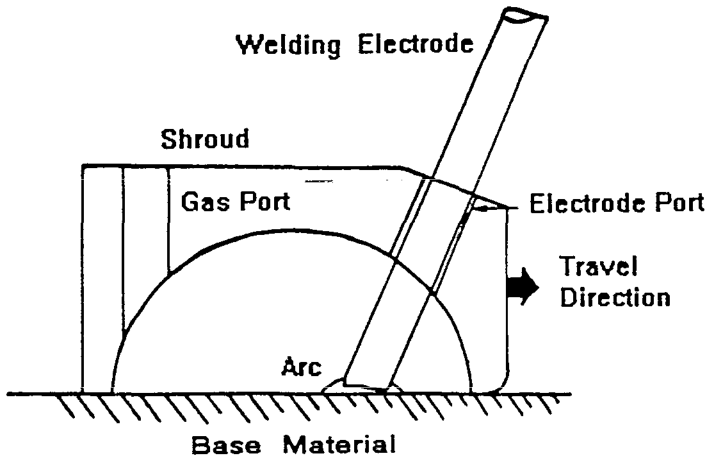
Underwater manual GMAW for dry habitats was first developed in the USSR in the 1950s, with welding capabilities reported up to a depth of 200 ft. GMAW is similar to FCAW with the exception of the consumable electrode (welding wire) chemistry and design. FCAW utilizes a hollow welding wire so that arc stabilizers, gas and slag formers, and alloying elements can be added in the form of a powder. GMAW uses a solid wire with the appropriate alloy chemistry and uses an external shielding gas to protect the molten puddle.

GMAW has the advantage of high rates of deposition and increased welding speeds compared to SMAW or GTAW. GMAW can be used to weld in all positions and is easily automated.

SMAW

SMAW is easily used in large habitat welding chambers, although, with smaller portable chambers manipulation of the consumable electrode is restrictive and visibility may be poor. Special chambers such as a shroud or "Hydrobox" (Sub Ocean Services) have been developed specifically for SMAW to overcome some of the basic problems related to the process. Shrouded Metal Arc Welding was designed specifically for SMAW process and the "Hydrobox" is adaptable to most fundamental welding processes.

Shrouded Metal Arc Welding was developed in an attempt to shield the weld pool for manual underwater SMAW, as shown in Figure VI-25. The chamber fits around the end of the electrode and against the work piece allowing the gas created by the flux to encapsulate the molten pool. The gas pressure in the chamber displaces the water and allows for a slower cooling rate. Excess gas is allowed to escape through a vent, to prohibit a build up of pressure. Excessive pressure can push the shroud away from the work piece. The shrouded metal arc welding method has only been used in research applications, due to limitations, including visibility and difficulty in manipulating the electrode.



CHAMBER FOR SHROUDED METAL ARC WELDING PROCESS
Figure VI-25

The "hydrobox" is designed to enclose the diver/welders hand and arm along with the welding torch. Variations of this chamber have been utilized for SMAW, FCAW, GMAW and GTAW. An inert gas is used to displace the water from the chamber and to shield the welding process. Code quality welds with GMAW have been successfully conducted using this technique.

WELDING CONSUMABLES

The development of wet welding shielded metal arc (SMAW) electrodes has primarily dealt with improvements in waterproofing the flux coatings. In most cases, commercially available electrodes have been waterproofed with no significant changes to the core wire or flux compositions. Flux-cored arc welding (FCAW) development has been structured towards improvements in flux chemistry and sheath composition, in an attempt to improve arc characteristics and eliminate undesirable effects introduced by the wet environment.

Characteristics desired when analyzing wet welding electrodes includes the following:

- Arc stability.
- High-deposition rate.
- All position capability.
- Medium penetration in all positions.
- Arc starting and restarting.

Underwater wet welding requires attention to the same principles as surface welding: protection of the molten puddle, metal transfer and arc column. The effectiveness of the gaseous shielding produced by the decomposing flux and the bubbles formed by offgasing and the heat of the weld to protect the weld puddle are significantly reduced in wet applications. Slag formed by the flux is also less effective in protecting the molten puddle from the atmosphere, controlling the cooling rate and scavenging impurities. The advantage of SMAW over FCAW is the arc barrel produced by the unmelted portion of the flux, which effectively protects the arc, metal transfer, and the molten puddle, to some extent. The length of the arc barrel is dependent on the melting rate variations of the flux and core wire, welding polarity, and travel speed. FCAW has the advantage of high-deposition rate and automatic process control.

Waterproof Coatings (SMAW)

Waterproof coatings maintain integrity of the flux coating while the electrodes are submerged and prior to striking an arc. Waterproofing techniques involve dipping electrodes into paraffm wax, epoxy resin, enamel, varnish, paint, or similar compounds. Problems associated with some of these coating products and techniques include contamination of the water with burnt waterproofing agent remnants such as wax or plastic, poor arc starting and stability characteristics, and reduced visibility.

An alternate method of coating electrodes has been developed by EPRI to improve underwater welding. The new process utilizes a pressurized coating technique to enhance the integrity of the waterproof coating. The process involves pressurizing the electrode in an acceptable waterproofing material for an appropriate holding period, allowing the waterproofing media to permeate the flux. Deoxaluminate, spar varnish and clear polyurethane coatings have been successfully used. Utilizing a pressure equal to or exceeding the water pressure at the depth of the intended welding operation assures the integrity of the flux coating to the corresponding depth. Improvements that have been observed using this process include

- Electrodes can be waterproofed in bulk quantities as opposed to individually dipping electrodes.
- Complete and consistent coating is applied on each electrode
- Initial are starting and restarting capabilities are enhanced. Coatings remain intact throughout the welding process.
- Are stability is noticeably enhanced and welding range (volts/amps) is usually increased.
- Uniformity of the flux burn-off is improved.

Maintenance of water chemistry in a reactor vessel is critical during welding operations. Waterproof coatings and welding slags should not introduce halogen ions (halides), specifically chlorine, bromine, iodine and fluorine into the water or systems. Halogen ions generally cause a detrimental effect on the corrosion rate of austenitic stainless steel and should be closely monitored or eliminated from the waterproof coating. These elements attack the passive surface coating of stainless steel such as Type 304, and may induce crevice corrosion, resulting in pitting or cracking. Most filtration systems can eliminate small amounts of halogens. A water chemistry analysis is often times required prior to actual welding operations to determine the halogen content introduced into the water by the slags and waterproof coatings.

Core wire

When welding on unstabilized austenitic stainless steel, such as Type 304, precautions are taken to assure weld deposits do not exceed 0.04% carbon (weight percent) and exhibit a ferrite number (FN) of eight or greater.

Filler materials typically used for welding austenitic stainless steel are listed in Figure VI-26. In all cases, the filler material should be compatible with the base material and should provide corrosive resistance and properties corresponding to the base material. Electrode selection for SMAW applications may result in use of higher alloy materials than required for adequate corrosion and strength properties. Such selections are the result of electrode practical performance factors rather than mechanical and corrosion properties. One example would be the use of E309L or E316L on Type 304 or 304L base metal because a vendor's electrode in these compositions exhibited better performance than typically used E308L.

TYPICAL FILLER METALS FOR WELDING AUSTENITIC STAINLESS STEELS
Figure Vl-26

Stainless Steel Type	Recommended Filler Metal	
	SMAW	FCAW
304 or 304L	E347, E308L, E308	E308LT-X E347T-X E308T-X
316 or 316L	E316, E316L	E316LT-X E316T-X
347	E308L, E347	E347T-X E308LT-X

Note:

L- Designates low-carbon
X- Designates external shielding
(1- CO_2 , 2- Ar + 2%0_2 , or 3- No shielding)

FLUXES AND SLAGS

Slag formed when welding is usually monitored for halogens, such as iodine, bromine, chlorine and fluorine during formulation development. The flux contained in SMAW and FCAW electrodes are likely to contain sufficient amounts of calcium fluoride, which disassociates in the arc to form free fluorine ions. Recent FCAW development is structured around developing halogen free fluxes, with self shielding abilities.

The general function of the flux in SMAW and FCAW processes includes the following:

- Create a gaseous atmosphere for protecting the arc, metal transfer and molten puddle.
- Produce a slag cover to protect the molten puddle, control the cooling rate and scavenge undesirable elements in the weld puddle (deoxidize).
- Improve the electrical stability of the arc.
- Provide alloying elements (optional).

Typical elements that make up the flux chemistry and their functions are shown in Figure VI-27.

CHEMICAL COMPOSITION OF THE MAJOR INGREDIENTS IN ELECTRODE COATINGS AND THEIR FUNCTIONS
Figure Vl-27

Name	Chemical Composition	Major Functions
Silica	SiO_2	Slag former, slag viscosity control
Limestone	$CaCO_3$	Gas former, arc stabilizer
Lime	CaO	Slag former, slag fluidity control
Fluorspar	CaF_2	Slag former, slag fluidity control
Alumina	$A1_2O_3$	Slag former, arc stabilizer
Cellulose	$(C_6H_{10}O_5)x$	Gas former
Rutile	TiO_2	Slag former, slag fluidity control
Feldspar	$K_2O.A1_2O_3.6SiO_2$	Slipping agent
Talc	$3MgO.4SiO_2\ H_2O$	Slag former, slipping agent
Mica	$K_2O.3AI_2O_3.6SiO_2.2H_2O$	Arc stabilizer, slipping agent
Bentonite	Complex Al, Mg, Ca, Fe, Hydroxide	Binder, slipping agent
Carbonyl Methyl Cellulose	CMC	Slipping agent
Ferro-manganese	Fe-Mn	Alloying agent, deoxidizer
Sodium Silicate	Na_2SiO_3	Binder
Potassium Silicate	K_2SiO_3	Binder

Electrodes of the same classification, but from different manufacturers, may perform very differently. It is not unusual for electrodes that provide slightly "off chemistry" deposits to be selected for use because of their superior performance.

MATERIALS

Underwater wet welding studies for nuclear repair applications are presently aimed at austenitic stainless steels and nickel alloys (Inconel). Wet welding carbon and low-alloy steels are not being addressed at this time. When reactor components were initially manufactured, 300 series austenitic stainless steels were specified for most surfaces in contact with primary coolant water. Experience acquired in early operations suggested that 300 series materials were susceptible to stress corrosion cracking and strict monitoring of service temperatures, water chemistry and thermal cycling time were required. In response to the susceptibility of austenitic stainless steels in many environments, materials such as high-nickel alloy 600, 690, and 800 and stabilized austenitic stainless steels were examined.

Austenitic Stainless Steels (300 Series)

All documented underwater wet welding applications for the nuclear industry have been performed on austenitic stainless steel materials. Austenitic materials are known for their oxidation and corrosive resistance when compared to carbon and low-alloy materials. Austenitic stainless steel materials are an iron base alloy with a chromium content between 15 and 32% and nickel content ranging from 8-40%. Typical chemical compositions are listed in Figure VI-28.

The main disadvantage of austenitic stainless steels, such as 304 and 316, is their susceptibility to stress corrosion cracking when the alloy is subjected to an appropriate corrosive environment, tensile stresses and has susceptible microstructures. Stress corrosion cracking is not limited to alloys sensitive to intergranular corrosion. Most alloys exposed to an active corrosive environment and elevated temperatures may also be susceptible to localized pitting and cracking. The most aggressive corrosive environment which attacks susceptible microstructures involves halogen ions (halides) which are disassociated from such elements as iodine, bromine, chlorine and fluorine. Halogen ion attack the passive corrosion resistant layer, typical of austenitic stainless steels. Chemical compositions of the grain boundaries and bulk material of sensitized Type 304 stainless steel are compared in Figure VI-29. lichen the chromium is depleted under 10 wt. percent as a result of sensitization, a corrosive reaction can occur along the grain boundaries, called intergranular corrosion. To reduce the susceptibility of austenitic stainless steels, low-carbon and stabilized grades have been developed (Figure VI-28).

NOMINAL COMPOSITION OF WROUGHT STAINLESS STEEL & INCONEL ALLOYS

(Inco Alloys Int.)

Figure VI-28

	Nominal Composition (%)									
Type	**C**	**Mn**	**Cr**	**Ni**	**Fe**	**Cu**	**si**	**P**	**S**	**Other**
Austenitic Grades										
304	0.08 max	2.0	18-20	8-12	R	-	1.0	.045	.03	—
304L	0.03 max	2.0	18-20	8-12	R	—	1.0	.045	.03	—
316	0.08 max	2.0	16-18	10-14	R	—	1.0	.045	.03	2-3 Mo
316L	0.03 max	2.0	16-18	10-14	R	—	1.0	.045	.03	2-3 Mo
321 *	0.08 max	2.0	17-19	9-12	R	—	1.0	.045	.03	0.4 Ti min
347 *	0.08 max	2.0	17-19	9-13	R	—	1.0	.045	.03	0.8 Nb-Ta min
Inconel										
Alloy 600	0.04 max	0.2	15.8	76 min.	7.2	.1	.20	—	.007	—
Alloy 625	0.05 max	0.25	21.5	61 min.	2.5	—	.25	—	.008	.2 Al & .2 TV & 9.0 Mo
Alloy 690	0.05 max	0.50	27-31	58 min.	7-11	.5	.50	—	.015	—
Alloy 800	0.04 max	0.75	20.5	32.0	46.0	.3	.35	—	.007	.3 Al & 3T1

Note: * Stabilized grades & L - Low-carbon grades

High-Nickel Alloys

Inconel (Huntington Alloys) is a high-nickel chromium alloy used primarily for application where high temperatures and oxidizing or corrosive environments are present. Inconel alloys are primarily a nickel base material, 60 to 75% Ni, with a chromium content ranging from 13 to 25%. Inconel Alloy 600 was first introduced to overcome corrosion cracking problems associated with 300 series austenitic materials. Alloy 600 has exhibited good in-service results, although in specific corrosive environments and elevated temperatures corrosive attack has been observed. Inconel Alloy 800 is often used as a replacement for austenitic stainless steel in chlorinated water. Alloy 800 is highly resistant to stress corrosion cracking and has nearly negligible corrosive attack in fresh water. New to the market is Inconel Alloy 690, with improved corrosive resistance at elevated temperatures. Alloy 690 is reported to have the same favorable strength, metallurgical stability, fabricability, and welding characteristics as Alloy 600. Chemical compositions of typical high-nickel alloys are listed in Figure VI-28.

Welding nickel alloys, such as Inconel, requires similar processes and methods as those used for stainless steel. Nearly all welding processes have been used to weld Inconel in surface applications, although only SMAW and FCAW have been evaluated for underwater wet welding. Since most repair applications concerning Inconel involve locations unaccessible to divers, underwater wet welding processes have been focused toward automated or machine FCAW. Filler material is usually of a similar composition as the base material, although when cladding operations are performed the filler corresponds to the applicable in-service requirements. Electrodes are generally made with high-nickel (such as Nickel 200) core wire (SMAW) and sheath (FCAW), with alloying elements present in the flux.

Similar to stainless steel welding, it is critical to maintain a water tight seal in the flux coatings for SMAW and maintain dry welding wire for FCAW prior to initiating welding operations. Molten nickel alloy weld metals do not flow as easily as stainless steels, making the operating range of welding parameters narrower. Weaving techniques are generally used for surface applications to help induce flowing of the weld bead, although weaving tends to be impractical for most underwater applications due to fast freezing of the puddle. An appropriate travel speed and electrode manipulation must be used to maintain the arc ahead of the weld puddle. Travel speeds tend to be faster for both FCAW and SMAW processes in wet applications.

GRAIN-BOUNDARY AND BULK CHEMICAL COMPOSITION (WT%) OF SENSITIZED TYPE 304 STAINLESS STEEL
Figure Vl-29

	Fe	Ni	Cr	C	S	P	Mo	Mn	si	Cu
Grain boundary (AES analysis)	64.2	9.2	22.8	1.7	0.1	0.0	ND	ND	1.4	ND
Bulk (chemical analysis)	—	9.3	17.7	0.046	0.012	0.026	0.33	1.17	0.47	0.20

ND = not detected

CODES

Underwater wet welding was originally specified for temporary repairs or operations such as sealing leaking rivets, dock repair or applying a patch plate to some component that required little or no structural integrity from the weldment. Low-carbon and low-alloy steel structures have been subjected to minor repair, but the repairs were rarely relied upon to exhibit mechanical properties similar to surface welds. Rapid quenching of the molten weld puddle attendant with the underwater environment results in general decreases in ductility of 40%, or greater, while hardness of the heat-affected zone may increase many fold for low-alloy steels. Other factors including depth, welding consumable and related waterproofing, position, and a general inability to maintain surface-like minimal arc lengths can yield greater amounts of internal weld discontinuities. Porosity, slag and lack of fusion may appear in greater quantities and distribution than in similar surface welds, regardless of base metal, weld metal or welding process. Cracking may also be observed, in the low-alloy steels, with rapid quenching and/or hydrogen entrapment usually being responsible.

Even though underwater welding was used, on a limited basis, as a repair technique since the 1930s, only in the last decade has the technology been considered for nuclear power applications. In most instances, repairs or rework in the nuclear arena have been restricted to austenitic stainless steel components and fillet weld configurations. Components including reactor internals such as feedwater sparger and core spray assemblies, steam drier/separators, fuel pool liners and fuel handling devices have all been addressed. Original fabrication or installation of such components was conducted under a variety of code jurisdictions including noncode, ANSI, ASME, AWS, or combinations of these codes. Welding qualification testing for underwater repairs usually follows the original code of fabrication to the extent possible to comply with the individual plant's Final Safety Analysis Report (FSAR) or other document for repairs, but includes additional information and evaluations necessary to assure that an acceptable weld can be obtained for the intended service.

Even where noncode items have underwent underwater repair, the utility industry has usually chosen to conduct the testing and work in accordance with one of the recognized standards. Typically, AWS D3.6 or ASME Section IX, are followed and their criteria modified as required to meet site specific requirements.

American Welding Society D3.6

The American Welding Society first published a code in 1983, AWS D3.6-83 "Specification for Underwater Welding" for addressing underwater welding of low-carbon and low-alloy carbon steels. This document was further refined and a revision was issued in 1989. The effects introduced by the underwater environment such as wet vs. dry, position, welding parameter changes, quench effect on the molten puddle, and shielding are taken into consideration.

AWS D3.6 divides weldments into four different categories (Types A, B, C & O) for purposes of defining criteria for a given level of weldment properties and soundness. Each of the four weldment types is defined as follows:

Type A: Underwater welds intended to be suitable for applications and design stresses comparable to their surface counterparts by means of specifying comparable properties and testing requirements.

Type B: Underwater welds intended for less critical applications where lower ductility, greater porosity, and other larger discontinuities can be tolerated.

Type C: Underwater welds intended for applications where the load-bearing function is not a primary consideration.

Type O: Underwater welds that meet the requirements of another code or specification plus the requirements defined in AWS D3.6.

Physical testing and inspection criteria vary depending on the category of weldment. One of the major differences between AWS D3.6 and other codes is its recognition that the mechanical properties and inspection results of low-carbon and low-alloy steels will be affected by the underwater environment - especially with respect to nonmetallic inclusions, toughness, hardness, and ductility. Acceptance criteria for slag and porosity are more liberal, plus radii for bend testing take ductility reductions into consideration. Different criteria are provided for each type of weldment. Requirements are not provided for underwater welding of high-alloy materials or nonferrous alloys.

Figure VI-30 illustrates an example of the tests required for acceptance of weld procedure qualifications for each type of weld conducted in accordance with this code. The appropriate revision of AWS D3.6 should be consulted for specific details and requirements where use of this code is required.

ASME Section IX

ASME Section IX, "Welding and Brazing Qualifications," provides basic standards and test criteria for the qualification of welding procedures and welders/welding operators for the fabrication, installation, and repair of power piping and pressure vessels. In most cases, additional requirements are imposed by other sections of the ASME Code, or another code of jurisdiction for specific work activities.

This code was developed for surface work and does not address underwater welding or the unique variables imposed by the wet environment. Specifically, items including depth, increased flaw quantities, decreased ductility in low-carbon and low-alloy steels and intended service of the weldment(s) are not taken into consideration.

WELD PROCEDURE QUALIFICATION - NUMBER AND TYPE OF TEST SPECIMENS[A]
Source: ANSI/AWS D3.6-89, Specification for Underwater Welding
Figure VI-30

Coupon Weld Type	Thickness Tested in. (mm)	Visual (See 6.4)	Radio-graph (See 6.5)	Reduced Section Tensile (See 4.4.1)	Fillet Weld Shear (See 4.4.8)	All-weld-Metal Tensile (See 4.4.4)	Root Bends (See 4.4.3) (Note b)	Face Bends (See 4.4.3) (Note b)	Side Bends (See 4.4.3) (Note b)	Macroetch Test (See 4.4.2)	Vickers Hardness (See 4.4.6)	Charpy Impact (See 4.4.5)	Fillet Weld Break (See 4.4.7)
Plate Groove A	t<3/8 (9.5)	Yes	Yes	2	0	1	2	2	0	1	1	WM & HAZ	0
	3/8<t<3/4	Yes	Yes	2	0	1	Note b	Note b	Note b	1	1	WM & HAZ	0
	t≥3/4 (19)	Yes	Yes	2	0	1	0	0	4	1	1	WM & HAZ	0
Pipe Groove A	t≤3/8 (9.5)	Yes	Yes	2	0	1	2	2	0	1	1	WM & HAZ	0
	3/8<t<3/4	Yes	Yes	2	0	1	Note b	Note b	Note b	1	1	WM & HAZ	0
	t≥3/4 (19)	Yes	Yes	2	0	1	0	0	4	1	1	WM & HAZ	0
Plate Groove B	t≤3/8 (9.5)	Yes	Yes	2	0	0	2	2	0	1	0	None	0
	3/8<t<3/4	Yes	Yes	2	0	0	Note b	Note b	Note b	1	0	None	0
	t≥3/4 (19)	Yes	Yes	2	0	0	0	0	4	1	0	None	0
Pipe Groove B	≤3/4 (19)	Yes	Yes	2	0	0	2	2	0	1	0	None	0
	3/8<t<3/4	Yes	Yes	2	0	0	Note b	Note b	Note b	1	0	None	0
	t≥3/4 (19)	Yes	Yes	2	0	0	0	0	4	1	0	None	0
Plate Fillet A	All (Note c)	Yes	No	0	1	1	0	0	0	2	1	WM	1
Pipe Fillet A	All (Note c)	Yes	No	0	1	1	0	0	0	4	1	WM	4
Plate Fillet B	All (Note c)	Yes	No	0	1	0	0	0	0	2	0	None	1
Pipe Fillet B	All (Note c)	Yes	No	0	1	0	0	~~X~~ 0	0	4	0	None	4
Plate Fillet C	All	Yes	No	0	0	0	0	0	0	4	0	None	0
Pipe Fillet C	All	Yes	No	0	0	0	0	0	0	4	0	None	0
All 0	All (Note c)	Yes	Note d	Note e	0	1	Note e	Note e	Note e	1	1	Note e	Note e

Notes: < less than; > greater than; WM—weld metal; HAZ—heat-affected zone; ≤ = less than or equal to; ≥ = greater than or equal to

a. First position only. Qualification for additional positions will omit groove weld tensile, macro, Charpy tests, fillet weld shear strength tests, and all-weld-metal tensile tests.
b. Multiple pass fillet welds are considered qualified by a groove weld qualification. (See 4.3.2)
c. For plate or pipe between 3/8 in. and 3/4 in. thick, Inspector may specify root and face or side bends.
d. Groove welds only are radiographed.
e. Mechanical test requirements shall satisfy the specific standard referenced by the customer. Weld metal and HAZ Charpy toughness testing is required only if Charpy toughness is required of the base metal on both sides of the weld.

Source: ANSI/AWS D3.6-89, Specification for Underwater Welding

ASME Section IX has, however, been used as the base code for qualification of wet welding procedures in some applications. Tension and bend tests (as shown in Figure VI-31) are typically the only tests required from this "surface" code. Additional criteria such as metallographic and nondestructive examinations plus specification of additional essential variables to be observed during the qualification and implementation of the procedures are oftentimes required.

Although not yet available, requirements to address wet welding of austenitic stainless steel are under consideration at the subcommittee working group level for inclusion in ASME Section XI, "Inservice Repairs."

Code Implementation

Fabrication and installation of components prior to commercial operation were typically conducted in accordance with AWS, ASME, ANSI, noncode, or a combination of these criteria, as specified in the design specifications and construction permits. During the 1960s, 1970s and early 1980s it was not uncommon for noncode items to be welded in accordance with a given recognized code or standard. It was also not unusual to find structural work (AWS) being accomplished with piping criteria (ASME, etc.) or codes and vice versa. Where technically acceptable, performance of noncode or code work to a higher standard of quality was often times both prudent and economical.

The extent and variety of repairs being conducted or planned today were not contemplated during design and new construction, nor were the potential consequences related to "code of construction" selection considered. The potential or need for underwater repair and welding of critical components was not addressed or even considered realistic. Thus, no specific codes were developed to satisfy underwater welding needs for critical or nuclear safety related components.

Many underwater repairs have however been accomplished on components where as-welded integrity was important. Components including fuel pool liners and handling equipment, core spray and feedwater sparger piping (in vessel) have been addressed. Almost all of the underwater welded repairs have been on austenitic stainless steel. Qualification and implementation of welding procedures and welder/divers has been characteristically conducted in accordance with criteria blended from one or more existing codes. The following illustrates approaches used to date:

Construction Code[1]	Repair "Code"
Noncode	AWS D3.6, or ASME IX with applicable variables of AWS D3.6[2]
AWS D1.1[3]	AWS D3.6, or ASME IX with applicable variables of AWS D3.6[2]
ASME IX	ASME IX with applicable variables of AWS D3.6[2]

1. The construction code refers to the standard that was used to qualify the welding procedure and welders.

2. Controls on variables including qualified depth range, filler metal control, position, and confirmation weldments in excess of ASME IX requirements but relevant to the wet environment are characteristically specified.

3. AWS D1.1, "Structural Welding Code."

In application, austenitic stainless steel wet welding repair procedures and welder/divers have been successfully qualified to both the AWS D3.6 and ASME IX codes. Most of the wet repairs have involved fillet welds and have been qualified by either groove or fillet coupons in the positions to be encountered in the actual repair. Mock-ups simulating the actual repair situation are widely used to demonstrate both the effectiveness of the repair technique and the ability of the welder/diver to accomplish the repair.

No significant repairs to carbon steels have been attempted to date in a nuclear facility. Mechanical bend test requirements of ASME IX would probably not be achieved due to the ductility losses associated with wet welding of carbon steels. AWS D3.6, however, has established alternate test and acceptance criteria that ensures that a level of integrity can and has been established for particular weldments.

TENSION TESTS AND TRANSVERSE-BEND TEST
Source: ASME Section IX, Welding and Brazing Qualifications
Figure VI-31

Thickness T of Test Coupon Welded, in.	Range of Thickness T of Base Metal Qualified, in. [Note (1)] Min.	Range of Thickness T of Base Metal Qualified, in. [Note (1)] Max.	Thickness t of Deposited Weld Metal Qualified, in. [Note (1)] Max.	Type and Number of Tests Required (Tension and Guided-Bend Tests) [Note (4)] Tension QW-150	Side Bend QW-160	Face Bend QW-160	Root Bend QW-160
Less than 1/16	T	$2T$	$2t$	2	. . .	2	2
1/16 to 3/8, incl.	1/16	$2T$	$2t$	2	Note (3)	2	2
Over 3/8, but less than 3/4	3/16	$2T$	$2t$	2	Note (3)	2	2
3/4 to less than 1½	3/16	$2T$	$2t$ when $t < 3/4$	2 (5)	4	. . .	. . .
3/4 to less than 1½	3/16	$2T$	$2T$ when $t \geq 3/4$	2 (5)	4	. . .	. . .
1½ and over	3/16	8 (2)	$2t$ when $t < 3/4$	2 (5)	4	. . .	. . .
1½ and over	3/16	8 (2)	8 (2) when $t \geq 3/4$	2 (5)	4	. . .	. . .

NOTES:
(1) See QW-403 (.2, .3, .6, .9, .10) and QW-407.4 for further limits on range of thicknesses qualified. Also see QW-202.2 for allowable exceptions.
(2) For the welding processes of QW-403.7 only; otherwise per Note (1) or $2T$, or $2t$, whichever is applicable.
(3) Four side-bend tests may be substituted for the required face- and root-bend tests, when thickness T is 3/8 in. and over.
(4) For combination of welding procedures, see QW-200.4.
(5) See QW-151 (.1, .2, .3) for details on multiple specimens when coupon thicknesses are over 1 in.

Source : ASME Section IX, Welding and Brazing Qualifications

WELDING QUALIFICATIONS

Welding Procedures

Qualifying a welding procedure for underwater welding applications is basically the same as qualifying surface welds. There are two documents, Welding Procedure Specifications (WPS) and Procedure Qualification Records (PQR), used in qualifying a welding procedure.

A WPS specifies welding conditions and variables. The typical variables included in an underwater welding procedure specification include

- Welding process (SMAW, FCAW, etc.).
- Joint design, tolerances and surface preparation or configuration.
- Base materials.
- Filler material (consumables).
- Welding position (vertical, overhead, etc.).
- Depth of welding application (Figure VI-32).
- Electrical parameters.

DEPTH LIMITATIONS FOR UNDERWATER WELDING QUALIFICATION
(Figure VI-31 has been proposed for use in AWS D3.6 and ASME Section XI.)
Figure VI-32

Type of Welding	Max. Depth Qualified	Min. Depth Qualified
Dry Welding	X plus 33 ft	X minus 33 fit
Wet Welding with austenitic stainless steel filler metal	X plus 10 ft	X minus 33 ft
Wet Welding with other filler metals	X	X minus 33 ft

Notes: 1. X is qualification test depth.

2. For the maximum depth qualified, depth shall be measured from the lower extremity of the test weldment with a tolerance of plus or minus 9 in.

3. For the minimum depth qualified, depth shall be measured from the upper extremity of the test weldment with a tolerance of plus or minus 9 in.

The WPS includes all applicable code information and supplemental requirements of the utility and/or original equipment manufacturer (OEM). Critical applications require specifications or variables to be written in greater detail than noncritical applications. Variables are labeled as either essential or nonessential. Essential variables cannot be changed outside of a stated limit or qualified range without being re-qualified, while nonessential variables may be changed by revising the WPS.

The WPS is qualified by producing welded joints in accordance with the variables in the procedure specification. The welds are evaluated with procedure qualification tests for specific properties such as toughness, ductility and strength, which demonstrate established requirements. Typical methods of evaluation include

- Macroetch evaluatiton of weld properties
- Guided bend tests (face, root, side).
- All weld metal tensile tests.

The qualification tests should resemble actual in-service conditions of the weld joint. The extent of the testing and the number of samples prepared for testing are governed by the applicable codes and specification. All procedure qualification test results and evaluations are documented in the PQR, Procedure Qualification Record.

Welder Performance Qualification

Welder performance qualification tests are used to determine the ability of a diver\welder to perform welding operations to a specified standard. The performance test utilizes the same welding process, materials and welding procedures representing the actual welding operation. Applicable codes or specifications such as AWS D3.6, ASME section IX, etc., utility and OEM requirements, usually determine the testing procedure.

Qualification welds are destructively tested (bend test, etc.) or nondestructively tested (radiography, etc.) and graded according to applicable codes and standards. Fillet welds, common for underwater welding applications, utilize fillet fracture tests and macroetches to verify weld integrity.

Welders may be required to re-qualify when changes are made in such variables as

- Welding Process.
- Filler metal (consumables).
- Welding position or technique (Figure VI-32).
- Joint configuration or detail (Figure VI-32).
- Material thickness.
- Depth of weld (Figure VI-3 1).

In most cases a welder will qualify in a position and with a material thickness that qualifies multiple positions and thicknesses. In some past repair operations, supplementary utility requirements have required performance qualifications for all thicknesses and positions and requalification of diver/welders for every repair application. Performance qualification records must be documented for each certified or qualified welder and submitted and approved by the utility prior to any underwater activity. In some instances, diver/welders are required to weld a mock-up specimen in all qualified positions in addition to code performance qualification requirements.

Material Qualification

Consumables such as welding electrodes, slags, and waterproofing must meet standards set by the applied code, utility, and/or the OEM. Ferrite content of weld deposits is verified by either an all-weld metal weld pad or one of the qualification/mock-up weldments.

POSITIONS FOR WELDER QUALIFICATIONS
Figure Vl-33

Qualification Test		TYPE OF WELD AND POSITION OF WELDING QUALIFIED			
		PLATE		PIPE[3]	
Weld	Plate or Pike Position[2]	Groove	Fillet	Groove	Fillet
Plate—groove	1G	F	F,H	F	F,H
	2G	F, H	F,H	F,H	F,H
	3G	F, H, V	F,H,V		F,H
	4G	F, OH	F, H, OH		
	3G & 4G	All	All		F,H
Plate—fillet	1F		F		F
	2F		F, H		F,H
	3F		F, H, V		
	4F		F,H,OH		
	3F & 4F		All		
Pipe—groove	1G	F	F, H	F	F,H
	2G	F,H	F, H	F,H	F,H
	5G	F,V,OH	F,V,OH	F,V,OH	F,V,OH
	6G	All	All	All[4]	All
	2G&5G	All	All	All[4]	All
	6GR	All	All	All	All
Pipe—fillet	1F		F		F
	2F or 2FR		F, H		F,H
	4F		F,H,OH		OH
	5F		F, H,V,OH		F,H,V,OH

Notes:

1. Position of welding: F-flat, H-horizontal, V-vertical, OH-overhead.
2. Positions as defined in 4.2.3. ANSI/AWS D3.6-89.
3. Plate qualifies pipe and tubing over 24 in. (610 mm) in diameter.
4. Except complete joint penetration groove welds in tubular T-, K-, and Y-connections.

Source: ANSI/AWS D3.6-89, *Specification for Underwater Welding.*

SPENT FUEL POOL LINER AND GATE REPAIRS Figure VI-34		
Plant	**Date**	**Code**
Byron	9/89	
Pallisades	9/80	
Peach Bottom	4/86	ASME IX
Salem	1/80, 4/80 & 3/81	ASME IX
Davis-Besse	2/91	
Yankee Rowe	4/81	
Brunswick	10/81 & 11182	
Oyster Creek	2/86	
Duane Arnold	11/80	
Almaraz	2/92	ASME IX
McGuire	10/85	ASME IX
Hatch	4/88	AWS D3.6
Rancho Seco	4/84	AWS D3.6
Haddam Neck	1/88	
Millstone	6/89	

RERACK/REWORK OF SPENT FUEL POOLS Figure VI-35	
Plant	Date
Farley 1 & 2	8/84
ANO 1&2	7/81,3&5/83,2/84,9/85
Calvert Cliffs	7/81
Indian Point 2	2/82
Oconee 1 & 2	6/79,12/80,2/88
St. Lucie	6/87
Duane Arnold	6/76 thru 7/90
Fitzpatrick	9/81, 7/82
Nine Mile 1	5/78
Millstone 1&2	5/77,10178,2186
Peachbottom 2&3	5/86
Salem	2/81
Ginna	10/86
Chin Shan 1&2	5/87
Davis-Besse	10/80
Vermont Yankee	3/78, 4/81
North Anna	4/78, 6/85
Kewaunee	12/78
Yankee Rowe	4/81
Robinson 2	2/82,6/83,2/89,5/90
San Onofre	10/70 thru 2/91
McGuire	82-88
Oconee	82-88
Trojan	--
Laguna Verde	5/91
Hope Creek	9/90

STEAM DRYER/SEPARATOR & RELATED REPAIRS
Figure VI-36

Plant	Date	Code
Oyster Creek	12/83. 2/86, 9/86	ASME IX
Cofrentes	2/89	ASME IX
Grand Gulf	9/90	ASME IX
Duane Arnold	2183	
Nine Mile 1	4/83	ASME IX
Susquehanna	2/84 10/87, 10/89	AWS D3.6 Type O & ASME IX
Kuo Sheng	11/89, 2191	
Browns Ferry	4/89	ASME IX
Vermont Yankee	9/84	
Pilgrim	8/87	
Lasalle	3/91	
Laguna Verde	11/91	ASME IX
Haddam Neck	1/88	
WNP-2	4/88	AWS D3.6
Peach Bottom 3	10/88	AWS D3.6
Hatch 1	11/88, 4/91	AWS D3.6
River Bend	11/90	AWS D3.6 Type O & ASME IX

CORE SPRAY PIPING REPAIRS
Figure VI-37

Plant	Date	Code
Cofrentes	6/90	ASME IX
Brunswick	9/91	ASME IX

FEEDWATER SPARGER NOZZLE REPAIRS
Figure Vl-38

Plant	Date	Code
Susquehanna 2	4/88	AWS D3.6 Type O
River Bend	3/89	AWS D3.6 Type O

THERMAL SHIELD REPAIRS
Figure Vl-39

Plant	Date
Haddam Neck	1/88 11/89
Beaver Valley	6/88
Main Yankee	4/90

MISCELLANEOUS COMPONENT REPAIRS
Figure VI-40

Plant	Date
Fuel Transfer System Repairs	
St. Lucie	4/80
Crystal River	6/85
Hanford Site	7/82
W Idaho Nuclear	6/87
ANO 1 & 2	11/83
Pilgrim	11/83
Millstone	6/89
Fuel Transfer Cart Repairs	
Davis-Besse	6/84
Oconee 1&2	12/81
Crystal River 3	7/85
North Anna	7/82, 6/84
Fuel Upender Repairs	
Crystal River 3	4/85
Farley 2	10/86
Fuel Prep Machine Repairs	
Limerick	11/88
Torus Tube Drain Line Repairs	
Pilgrim	8/87
Spent Fuel Pool Valve Repairs	
Three Mile Island	8/81,5/85,4/86

SPECIALIZED MACHINING & CUTTING WITH EDM AND MDM OR PLASMA ARC CUTTING Figure VI-41		
Plant	**Technique**	**Dates**
ANO 1	EDM	7/86
Savannah River	EDM	85
USNRC/TMI II	MDM	2/90
Haddam Neck	MDM	4/90
Haddam Neck	EDM	N/A
Kozloduy-Bulgaria	EDM	11/91
KORI-I (Korea)	MDM	10/90
Trojan	EDM	85
Point Beach I&II	EDM	87
Beaver Valley	EDM	88
Ringhals	EDM	88
Zorita (Spain)	EDM	10/81
Yankee Rowe	EDM	4/92
Cooper	MDM	10/91
Duane Arnold	MDM	90
Hatch	MDM	N/A
Elk River	Plasma	72
Three-Mile Island	Plasma	88-89
San Onofre II & III	EDM	6/89
McGuire	Plasma	85

Repair Mock-Up Training

A full scale mock-up of actual repair conditions prepare and train diver/welders for the actual repair procedure. Simulating the repair with realistic mock-ups reduces actual repair time and significantly enhances the safety and quality of the overall operation. Mock-up training is used to develop repair sequences and allows for unforeseen problems to be worked out ahead of time. Mock-up training also allows the divers to become familiar with restrictions produced by exposure protection shields and work platforms which may obstruct mobility and local access to the work area.

During mock-up training, the entire repair sequence should be simulated, including communications, repair preparations, cutting and welding, clean-up, monitoring and inspection. The equipment shielding and work platform used in the repair simulation should correspond to the equipment intended for the actual repair operation. All diving personnel, including radiation (health physics) staff should be present during mock-up training, so that a complete evaluation and optimization of the repair procedure and equipment can be obtained.

The intent of mock-up training is to evaluate and become familiar with the following:

- Communication and monitoring equipment.
- Effectiveness of platform and shielding configurations.
- Equipment, tools, fixtures and jigs.
- Diving work schedules.
- Diver accessibility to work area (weld joints, etc.).
- Welding and cutting operations
- Retention of cutting particles, welding dross and clean up capabilities.

In many cases, welding qualifications and material testing are done concurrent with mock-up training.

Repair Preparation and Equipment

Activities involved during preparation of an underwater repair may represent the majority of the operation. As stated above, welding procedures, and performance and material qualifications must be completed prior to any repair application and, in many cases, a full mock-up and training session is appropriate. Providing for optimized work conditions and equipment usually results in increased working efficiency and reduced outage time. Additional preparation for underwater repair operations covered in this section include platform and radiation barrier requirements, decontamination and clean up operations, and general equipment.

Hand tools used in surface welding and cutting operations are typically used underwater. Electrical power tools, on the other hand, are replaced with the equivalent pneumatic or water powered tools. Due to the improved visibility, water powered tools are preferred over pneumatic powered equipment which produce an excessive amount of bubbles during operation. Hydraulic tools are not generally used for minor manual operations.

Water powered tools are generally controlled by electric drive motors and high-pressure, positive displacement pumps. Pneumatic tools are operated with high-pressure air supplied by a compressor or bottled compressed air and manifold systems.

Fit up techniques may include pneumatic or mechanical devices. Locking pliers and C-clamps are also typically used. In many cases, weld joint preparation can be performed on material topside, prior to diving operations. Underwater joint preparation can be achieved with tools such as

- <u>Pneumatic deburring tool</u> - Used for surface and underwater preparation before and after welding, to clean up rough edges, weld spatter, etc.
- <u>Pneumatic chipping gun</u> - Used to clean up between weld passes.

- water or pneumatic powered grinders - Used when significant quantities of material are to be removed in joint preparation or in weld removal. Underwater grinders can also be used for light cutting by replacing the grinding disc with a cutting wheel.

Underwater mechanical cutting operations, such as drilling, machining, cutting, etc. are covered in Section 3.

All equipment and tools, including welding consumables, should be inventoried prior to entering the water. Upon leaving the water, the equipment should again be inventoried. Foreign objects, such as hand tools and welding electrodes, lost in the reactor vessel can be detrimental to normal operations of the nuclear facility. Case History Number 1, Appendix VII, illustrates the damage caused by foreign objects to the feed water sparger. Most tools and loose equipment are attached to retrieving lines (lanyard) when work is done within the reactor vessel or other critical area. A basket is typically used to collect electrode stubs and large cutting particles. Foreign object retrieval methods should be considered prior to diving operations. Most operations place a fine wire mesh screen or cloth under the immediate work area to collect fallen hand tools and debris from the work area, such as slag and residue from grinding, cutting and welding.

Work platforms are erected to conform to the geometry of the work location. Platform design should provide stability to the diver and allow the diver(s) easy access to the work area. Platforms can either be made stationary, with work being moved to the platform, or can be mobile and moved to repair locations. Platforms should consider the following:

- Platforms should have a grated floor and be contained on at least two sides with hand rails or radiation shielding, as needed, and made from corrosive resistant material, such as aluminum or stainless steel.

- Easy access to the platform and to the work area. Divers should be able to enter the platform from the side opposite of work area.

- Low exposure area where divers can run confirmation welds and remain submerged during unscheduled down-time (< 5mr/hr.).

- The work area should be accessible through an access window which does not confine the diver, but provides appropriate limitations, if necessary.

- The platform should be easily mounted next to the work area and provide divers with maximum support.

All surface work should be restricted from the immediate area, to assure the safety of the divers from falling objects. An access platform and ladder at the surface of the water will allow the divers to enter and exit the water more readily and provide for easier retrieval of equipment. A means of lowering and maneuvering larger components, equipment and platforms, such as over-head cranes and/or portable gantries, should designated at the work site. All areas where gases produced by welding, cutting, and repair techniques could be entrapped should be vented to eliminate potential explosive environments.

In most cases, water alone will provide an appropriate amount of shielding although in-vessel repairs and heavily contaminated components may require additional shielding. Shielding should be placed between the diver and radiation source, preferably as close to the source as possible. The shielding effectiveness of water is 1000X greater than that of air and 18 in. of water is as effective as 1.5 in. of lead. Appropriate shielding configurations (water and other radiation barriers) can significantly lower individual exposure dosage, allowing divers longer down-time, resulting in greater work efficiency and reduced outage time.

Lead and steel are commonly used for shielding purposes. Lead is usually encapsulated with a wear resistant surface, such as steel or nylon-reinforced polyvinyl chloride (PVC), to lower surface contamination levels and to reduce loss of lead fragments. Typical material attenuation properties are shown m Figure VI-42.

RADIATION ATTENUATION PROPERTIES OF COMMON MATERIALS

Figure Vl-42

Material	**Thickness (inches)**	**Reduction Factor**
Lead Sheet	1/4 1/2	.75 .55
Water	18	≈.2
Carbon Steel	1 2	.65 .32
Lead and Steel	2 in. lead encapsulated with 1/4 steel	.1

In Case History Number 4, Appendix VII, an aluminum core barrier was fabricated to prohibit divers from entering high-radiation areas measured near the core of the reactor. Case History Number 7 utilized 2-in. lead plates encapsulated in l/4-in. carbon steel plates to effectively reduce the radiation levels by 90%.

If the work area does not allow for additional shielding, due to limited space and accessibility, work platforms can be designed to effectively shield the diver. The platform can either be made with appropriate material for shielding or shielding can be hung from the platform. Platforms can be made with sliding doors, limiting access to only the immediate work area and restricting divers from extending their upper body and head past acceptable stand-off distances. In some cases, ropes or nets have been used to designate "hot" zones and to limit diver access to these areas.

The main objective of decontamination is to reduce radiation levels to ranges where repair activities can be performed to meet ALARA goals. Most underwater operations do not require decontamination of components and rely specifically on the shielding abilities of the water environment. Prior to every diving activity, a radiation survey should be conducted to determine if decontamination is necessary. The surveys are used to map out radiation levels in the work area, so restrictions can be placed on dive activities in highly contaminated regions.

Sources of radiation include activated fission products from the nuclear fuel, activated structural material in core support structures and reactor walls, and contaminated corrosion particles distributed throughout the recirculation loop and other systems. The contaminated corrosion particles are distributed throughout the entire plant and become an integral part of the corrosion films on nearly all submerged components, as seen in Figure VI-43. Radiation levels from distributed contaminated particles are usually dealt with by means of shielding and/or decontamination when repair activities are affected.

CONTAMINATED CORROSION FILM LAYERS
Figure V1-43

~ 0.1 mils Total Thickness	Loosely Bonded Film Comprised of Corrosion and Fission Products	50% of Contamination
	Adherent Oxide Layer Comprinsed of Corrosion Products in Oxide Matrix	≤50% of Contamination
Base Metal		

In most underwater operations, only the removal from the outer layer of the contaminated corrosion film (Figure VI-43) is attempted. The loose outer layer is easily removed and in many cases will reduce up to 50% of the radiation levels.

Waterjet blasting, often called hydrolazing, is one of the most efficient methods of decontamination for underwater applications of large components. Other methods, such as electropolishing, flapper wheel cleaning, manually scrubbing and chemical decontamination work well but are usually not practical for most underwater situations. Waterjet blasting can utilize up to 10,000 psi, typically 2000 psi water pressure, with or without grit additions to the water. If grit is used, an acceptable means of recovering the grit particles is required.

Waterjet blasting directs a small stream or fan of high-velocity water against the surface to dislodge and remove the loosely bonded outer layer of contaminated corrosion film. The gun used for waterjet blasting has the advantage of a long handle, not requiring personnel to be in close proximity of the work.

Underwater vacuums are used in repair activities for initial, m-process and final clean-up operations. In many cases, work areas are contained and vacuums are positioned close to the work so that particles can be picked up as they are created, reducing the cleanup area and time.

Recovery of welding and cutting dross, grinding particles, mechanical cutting chips, etc. are critical to underwater repair operations. Accumulation of particles in such areas as the recirculation system, act as abrasives and can be detrimental to pipe seals, valves, pumps, etc.

The general equipment used for underwater vacuuming includes

- Submersible, high-volume, positive displacement, water pumps, typically in the range of 200 gpm.
- Noncollapsible suction hoses, usually nylon-reinforced polyvinyl chloride (PVC).

- Supplementary filtration systems or pool filtration systems can be used, if appropriate, for specific repair applications.

- Filter screens sized for the particles or dross created by the process

Experience Reports

A significant amount of underwater work has been conducted in the nuclear power industry. The cutting/machining and welding approaches used vary almost as widely as the repair/replacement/maintenance tasks that have been undertaken. Some tasks have been accomplished with tools as simple as a grinder or other apparatus on a long pole to completely remote operations involving highly sophistocated electronic positioning devices and cutting/welding accesories. All welding to date in the nuclear arena has been accomplished in the manual mode with diver/welders. On tasks that require other than the simplest long reach tooling, where access is available and radiation levels are tolerable, work by divers has been found to be far faster and cost effective than designing and implementing remote devices.

A variety of components and systems including fuel pool liners, fuel handling equipment, fuel storage structures, and reactor vessels and internals that have undergone underwater repairs or evaluations are listed in Appendix VI. Brief details including the plant, date, code, and service vendor or other appropriate information are provided in Appendix VI to illustrate the general amount of work that has been done from an underwater perspective. The tabulations are not all inclusive, but do represent work done primarily by those parties who have been very active in the industry plus exercise underwater expertise in both cutting/machining and welding. Activities related to inspection or accomplishing work by remote manipulation of mechanical devices are not included.

Further illustrations of successful work activities are included as case histories in Appendix VII.

Appendix VII

Case Histories

CASE HISTORIES

CASE HISTORY NO. 1

Utility: Gulf State Utilities, River Bend Station, St.Francisville, LA. March 15, 1989.

Vendor: Global Divers and Contractors, Inc. 2)

Repair: A damaged nozzle on the feedwater sparger was discovered during a general underwater visual inspection. A foreign object had worn a hole near the connection of a nozzle, and was protruding through the hole. The foreign object and nozzle were removed and a patch was placed over the hole in the sparger pipe. In addition a second object was located and removed from the sparger pipe. The foreign objects were identified as scaffolding knuckle clamps. Repair operations were completed within the reactor vessel loaded with irradiated fuel.

Repair Description: A circular patch, was welded over the hole remaining after the nozzle was removed from the sparger. The hole was approximately 1.5 m. (38 mm) in diameter and oval in shape. The hole and patch were prepared with a 60 degree included angle, 1/16 to 1/32 in. (.8 to 1.6 mm) root opening and a 3/32 in. (2.4 mm) root face. All welds were performed in the flat position, with 80 to 85% penetration. Welding parameters were held at approximately 150 amps and 26 volts for the root pass. Repair was considered to be permanent.

Depth of Repair: 43 feet (13.1 m).

Water Conditions: Not Stated

Radiation Levels: 5 r/h (roentgen) on contact and 1.5 r/h at 12 in. After hydrolasing (section 3) levels were at 3 r/h on contact and 325 mr/h at 12 in.

Total Exposure: 1.85 man-rem for 24 dives and 24.3 hours down-time. 12 to 202 mrem per dive were recorded, with 285 mrem being the maximum exposure to one diver.

Materials: Sparger - 6 in. (152 mm.) diameter pipe, schedule 80 SA312, Type 316 L.

Electrodes: AWS A5.4 classified material - Type 316L, with a proprietary waterproof coating; supplied by Global Divers.

Weld Qualifications: Welding procedure qualifications were qualified under AWS D3.6-83, for type "O" welds. ASME Section IX was used for essential variables not effected by UW environment. The weld deposit was performed to SFA 6.4 criteria, for certification of the UW welding electrodes. The welder/divers qualified in the 3G position on a 3/8 in. groove weld with backing, running downhill, under ASME Section IX codes. The test were run at depths of 5 and 20 ft.(l.52 and 6.09 m). By using a combination of AWS D3.6 and ASME Section IX, weld procedures were qualified for all positions and for depths ranging between 5 and 53 feet. Diver/welders were qualified in the 3G position on 3/8 in. groove weld in accordance with ASME Section IX.

Personnel: Ten diver/welders were qualified for the repair operation, additional personnel not stated.

Equipment:

Welding Equipment: An inverter type DC power supply was used for all welding procedures. Standard weld leads with a proprietary electrode holder and ground clamp were connected through a knife switch at a master control station.

Diver Equipment: Divers wore full rubber dry suits including integral feet and water-tight gloves and welding helmet. An umbilical line was used to supply breathing air and a hard wire communications line. In addition each diver was connected to a pre-measured tether line to limit his decent. The breathing air was supplied by a main compressor and a back-up compressor.

Monitoring Equipment: Video equipment, fiber optics, T.V. monitor and UW camera were used for initial, intermediate and final inspection records.

Other Equipment: Initial cleaning was performed using a hydrolasing process (section 3), to further reduce radiation levels. A positive displacement water pump was used to run a water grinder and arc-water gouger (section 2). A pneumatic grinder with debarring tool was used for final joint preparation and a pneumatic chipping hammer was used for cleaning weld interpasses. A water vacuum (100 gal./min) was used to recover weld slag, and grinding and cutting particles.

Mock-up: A complete mock-up of the sparger pipe and rector wall were developed and placed in 33 ft. of water to simulate the actual diving conditions. The mock-up was used to develop joint configurations, train the divers and to develop a time conscious schedule of work details.

Radiation Barriers and Work Platform: A shielded work station was utilized to protect divers from radiation. The work station consisted of a three sided platform with grated floor. The sides were made from 1 in. thick carbon steel. An additional 1 in. shield was placed between the reactor wall and the sparger. A drop cloth was placed under the work area to assure no loose material or objects fell into reactor core.

Safety Precautions: Divers were in contact at all times with the dive supervisor and welding power was contacted on divers instruction only. The divers were hooked to a tether line which restricted decent below the work area. In addition the divers wet suits were leaked tested prior to each dye. Individual radiation was monitored as described in section 7. Real-time monitoring of selected body parts was continuously monitored due to possible high dosages and body position was altered regularly to reduce exposure.

CASE HISTORY NO. 2

Utility: Pennsylvania Power and Light, Susquehanna Unit 1, October 1987.

Vendor: Global Divers and Contractors, Inc. (8)

Repair: Fatigue crack in the hood and end panel of the steam dryer had a fatigue crack 54 in. long, running along the original weld. The crack had opened up 3/4 in. The repair required the crack to be closed, ground out and rewelded. In addition, a reinforcement plate was designed to assure the crack did reoccur. Reinforcement plate was placed over the repair weld and welded in place. As a precaution three similar locations were reinforced in the same manner. Repair was performed in the equipment pool.

Repair Description: The original corner weld joint was ground out to form a 90° V-groove, to improve accessibility. Four in. tack welds were placed on 12 in. centers to hold plates in the original position. The parameters were approximately 100 amps and 27 volts with a travel speed of 11-12 ipm. The weld was then ground flush so the reinforcement plate would sit flat over weld area. The reinforcement plate was then tacked in place and welded with a 3/16 m. fillet weld on one side and a 1/4 in. groove weld on the other side. The parameters were approximately 115 amps and 27-35 volts, with a travel speed of 8-11 ipm. DC straight polarity was used for all welding operations. A penetration of .08 in. (2 mm) was required and achieved for the reinforcement plates.

Depth of Repair: 6 to 14 feet (1.8 to 4.3 m.)

Water Conditions: Water temperature was originally above 90 °F and was required to be reduced below 90°F (31°C) prior to diving activities. Temperature was reduced to 89°F, by additions of demineralized water.

Radiation Levels: 6 r/h were measured on contact and 1.5 r/h (roentgen) at 12 in. of water.

Total Exposure: 6.7 man-rem was recorded for 20 dives and 50 hours of down-time. Individual exposures ranged from 140 to 1000 mrem. 100 to 120 man-rem were estimated if repair was done in dry conditions with a crew of 80 welders instead of the ten used.

Materials: Plate thicknesses consisted of 1/8, 3/16 and 1/4 in. Type 304L stainless steel plate.

Electrodes: Originally welded with Type 308 filler metal (GTAW). Repair weld was made with a AWS A5.4 Class E316L filler material, with a proprietary waterproof coating (Global Divers). Electrodes were mild steel core with alloying elements in the coating.

Weld Qualifications: A weld procedure for underwater wet welding the steam dryer was developed in accordance with AWS D3.6, for type "B" welds. The welder/divers were qualified for fillet and groove welds. The groove welds were performed downhill in the 3G position, on a 1/8 to 1/8 in. and 1/4 to 1/4 in. plates. The fillet welds were performed in the 2F and downhill 3F positions on 1/8 to 1/8 in. and 3/16 to 3/16 in. T-joints and 1/8 and 3/16 n. lap joints. The test were performed at a depth of 10 feet (3 m).

In addition, welder/divers were required to run a practice weld bead to adjust the welding parameters, then run a 12 in. long confirmation weld on a mock-up of the actual joint configuration, prior to each weld joint. This weld was inspected and accepted each time by the utility, before any welding was done on the steam dryer.

An all-weld deposit was checked to determine the as-welded ferrite number. A minimum ferrite number of 8 was required. Chemical analysis was performed on slags and waterproof coating to determine the halogen and sulfur content.

Personnel: Ten diver/welders were qualified for the repair operation. In addition, two divers and a project manager were on site. The crew was assisted by a 6 man crew of station mechanics, four health physic technicians, and two video equipment operators.

Equipment:
Welding Equipment: An inverter type DC power supply was used for all welding procedures. Standard weld leads and ground clamps along with a proprietary UW electrode holder were connected through a knife switch at a master control station.

Diver Equipment: Divers wore full rubber dry suits including integral feet and water-tight gloves and welding helmet. An umbilical line was used to supply breathing air and a intercom system was used for continuous communication to diver tender. The breathing air was supplied by a main compressor and a back-up compressor.

Monitoring Equipment: Video equipment, T.V monitor and UW camera were used for recording repair procedure and for final and intermediate inspection.

Other Equipment: A water powered grinder and a pneumatic chipping hammer were used for joint preparation and cleaning welds, between passes. A water vacuum (100 gal./min) was used for recovery of weld slag, grinding and cutting particles, and remanents of waterproof electrode coatings. Manual and pneumatic jacking bars were utilized for material positioning.

Mock-up: All tests were completed on a mock-up of the actual joint configuration.

Radiation Barriers and Work Platforms: A working platform was stationary and built to the contour of the steam dryer. The steam dryer was rotated around the work platform. Radiation barriers were not specified.

Safety Precautions: Divers were in contact at all times with the dive tenders and welding power was contacted on divers instruction only. In addition the divers wet suits were leaked tested prior to each dive. Individual radiation was monitored as described in section 7. Real-time monitoring of selected body parts was continuously monitored due to possible high dosages and body position was altered regularly to reduce exposure. The low dose area of the work platform was used for confirmation welds.

CASE HISTORY NO. 3

Utility: The Grand Gulf Nuclear Station, Grand Gulf 1, October, 1990.

Vendor: Brand Utility Services (formerly Nuclear Underwater Construction) (47).

Repair: The original repair application involved a right guide bracket on the steam dryer's lower ring which was accidentally damaged. During inspection of the bracket additional damage was found, which included separator tubes, shroud head bolts, retaining cans, gussets and stiffeners of the steam generator. This was considered to be in immediate emergency repair. The damage included broken welds on gussets and stiffener, buckled stiffeners and bent retainer can. Much of the repair involved rewelding the cracked welds, removing loose part potentials and replacing any needed gussets or stiffeners. Repair was done in equipment the pool.

Repair Description: The separator can was removed by removing the welds along the lower guide ring stiffener and by cutting off the standpipe. This was accomplished with the use of UW plasma arc cutting and pneumatic grinding equipment. The loose ends of the stiffener were then removed to eliminate loose parts and the standpipe was plugged off by welding a cap over the cut end. Eleven shroud head bolts were removed and nine bolt holes were elongated with the use of underwater plasma, so that bolts could be replaced. The broken gussets were repositioned and rewelded. The welds on the right guide bracket were 1/4 in. fillet welds and welded in the 3F position. The welds on the gussets, stiffeners and standpipe were 1/8 and 1/4 in. fillet welds, all welded in the 2F position.

Depth of Repair: Approximately 10 feet.

Water Conditions: Not Stated

Radiation Levels: Not stated.

Total Exposure: 4.5 man-rem total exposure for 15 dives and 42 hours down-time, for the emergency repair job and 5 dives and 8 hours down-time for guide bracket repair.

Materials: Type 304 S.S.

Electrodes: E316L-16 and E308L-16; 3/32, 1/8 and 5/32 in. diameter.

Weld Qualifications: Weld procedure qualifications utilized ASME Section A. All Welder/Divers were certified for the 2G, 3G and 4G positions on 304 S.S. in a 1/16 to 1/2 in. plate thickness range, in 10 feet of water. This qualified the Welder/Divers for fillet welds of all thicknesses. All Welder/Divers also demonstrated their abilities m a full-size mock-up prior to actual repair applications.

Personnel: Three diver\welders were used for each job. Other personnel was not stated.

Equipment:
Welding Equipment: Underwater plasma cutting utilized a 100 amp plasma system, the welding equipment was not stated.

Diver Equipment: Not Stated.

Monitoring Equipment: Not Stated.

Other Equipment: A pneumatic grinder was used for removing welds.

Mock up: All tests and certifications were completed on a mock-up of the actual joint configurations.

Radiation Barriers and Work Platform: Not Stated.

Safety Precautions: ALARA exposure guidelines were in effect.

CASE HISTORY NO. 4

Utility: Pennsylvania Power and Light, Susquehanna Unit 2, May 1988.

Vendor: Global Divers and Contractors, Inc. (3,8)

Repair: The Feedwater sparger discharge nozzles on two feedwater sparger headers were damaged due to a misalignment during outage activities. All damage was considered to be minor except one nozzle, which was kinked and flattened with a tear 1.5 in. long, which could possible propagate. It was decided that the tear be patched and the kink to be repaired by wet welding. Repair was completed within the reactor vessel loaded with irradiated fuel.

Repair Description: The tear in the nozzle was repaired by welding a vertical build up patch parallel to the tear. The indentations or kinks were repaired by a horizontal weld overlay which extended 1/2 in. beyond each end of the indentation.

Depth of Repair: 43 feet

Water Conditions: Not Stated.

Radiation Levels: 0.2 r/h was measured in the area of welding operations, although 6 feet below the repair levels radiation increased to 1 r/h and to 1000's of r at 10 feet below the repair level.

Total Exposure: 323 mrem was recorded for 5 dives and 4 1/3 hours down-time.

Material: Type 316L stainless steel.

Electrode: E316L electrodes with a proprietary aluminum waterproof coating were utilized.

Weld Qualifications: Weld procedures were qualified in accordance with ANSI/AWS D3.6. Weld procedures were qualified for a depth range of 10 to 63 ft. All diver/welders were qualified at 33 ft and required to produce a mock-up weld of both repair applications (horizontal overlay and vertical build-up patch). The aluminum coated electrode were tested for halogens.

Personnel: Three diver/welders were qualified and tested for the repair operation. Other personnel were not specified.

Equipment:
Welding Equipment: An inverter type DC power supply was used for all welding procedures. Standard weld leads and ground clamps along

with a proprietary UW electrode holder were connected through a knife switch at a master control station.

Diver Equipment: Divers wore full rubber dry suits including integral feet and water-tight gloves and welding helmet. An umbilical line was used to supply breathing air and a intercom system was used for continuous communication to dive tenders. The breathing air was supplied by a main compressor and a back-up compressor.

Monitoring Equipment: Video equipment, T.V monitor and UW camera were used for recording repair procedure and for final and intermediate inspection.

Other Equipment: A water powered grinder and, a pneumatic chipping hammer and deburring tool were used for cleaning welds and weld preparation. A water vacuum (100 gal./min) was used to recover weld slag, grinding and cutting particles, and remanents of waterproof electrode coatings. A fine wire screen was placed under the work platform to catch all residues and particles.

Mock-up: All tests and certifications were completed on a mock-up of the actual weld applications.

Radiation Barriers and Work Platforms: A work platform was made of aluminum and suspended at the location area. Due to the lethal radiation levels below the divers' workstation, a physical core barrier was constructed, to assure against accidental mishap. The core barrier was constructed of aluminum structural material and grating.

Safety Precautions: Divers were m contact at all times with the dive tenders and welding power was contacted on divers instruction only. In addition the divers wet suits were leaked tested prior to each dive. Divers were hooked to pre-measured tether line, which was manned by three persons in case emergency retrieval was necessary. A second diver was required to be fully dressed and ready to enter the water at all times when diving activities were underway.

Radiation survey was conducted prior to the repair operations, and individual radiation was monitored as described in Section 7. Real-time monitoring of selected body parts was continuously monitored due to possible high dosages and body position was altered regularly to reduce exposure.

CASE HISTORY NO. 5

Utility: Pennsylvania Power and Light, Susquehanna Unit 1, Spring 1989.

Vendor: Global Divers and Contractors, Inc. (3,8)

Repair: An 18 in. long fatigue crack was discovered, during remote a video inspection. The crack was in the horizontal fillet weld between the top of the drain channel and the steam dryer support ring and continuing into the drain channel for another 3 in. Repair was performed in the equipment pool.

Repair Description: The cracked fillet weld was removed, the drain channel was repositioned and rewelded. The repair weld extended 2 in. past the original crack end. The crack protruding into the drain channel was stopped by drilling a 1 in. hole at the end of the crack.

Depth of Repair: 17 feet (5 m.)

Water Conditions: Not Stated

Radiation Levels: 1.6 r/h on contact and 200 mr/h (roentgen) at 18 in. was measured. Levels 4 feet below the work area were 2.8 r/h on contact and 200-300 mr/h at 18 in.

Total Exposure: 796 mrem for 5 dives and 5: 55 hours down-time.

Materials: Type 304L S.S.

Electrodes: Not Stated

Weld Qualifications: A previously qualified welding procedure in accordance with ANSI/AWS D3.6, used on the Unit 2 sparger repair was requalified for the 4F position for 1/8 to 1/2 in. and thicker austenitic stainless steel. The qualification was carried out at a depth of 33 feet so welding could be done at depths greater than 10 feet.

The diver/welders qualified at 33 feet in the 4F position. A mock-up was also used to test the hole drilling and crack retention technique. The welders were required to make a confirmation weld prior to each welding application.

Personnel: Two diver/welders were qualified for the welding procedures.

Equipment:
Welding Equipment: An inverter type DC power supply was used for all welding procedures. Standard weld leads and ground clamps along

with a proprietary UW electrode holder were connected through a knife switch at a master control station.

Diver Equipment: Divers wore full rubber dry suits including integral feet and water-tight gloves and welding helmet. An umbilical line was used to supply breathing air and a intercom system was used for continuous communication to dive tenders. The breathing air was supplied by a main compressor and a back-up compressor.

Monitoring Equipment: Video equipment, T.V monitor and UW camera were used for recording repair procedure and for final and intermediate inspection.

Other Equipment: Water powered grinders and pneumatic chipping hammer was used to clean weld interpasses and to prepare weld joints. A water vacuum (100 gal./min) was used to recover weld slag, grinding and cutting particles, and remanents of waterproof electrode coatings. A pneumatic drill and hole saw were used to drill the 1 in. hole for crack propagation retention.

Mock-up: All tests were completed on a mock-up of the actual joint configuration.

Radiation Barriers and Work Platforms: A work platform was built to the contour of the steam dryer. The platform was stationary while the steam dryer was rotated.

Safety Precautions: Divers were in contact at all times with the dive tenders and welding power was contacted on divers instruction only. In addition the divers wet suits were leaked tested prior to each dive.

Individual radiation was monitored as described m section 7. Real-time monitoring of selected body parts was continuously monitored due to possible high dosages. Body position was altered regularly to reduce exposure.

CASE HISTORY NO. 6

Utility: Pennsylvania Power and Light, Susquehanna Unit 2, Fall 1989.

Vendor: Global Divers and Contractors, Inc. (3,8)

Repair: An intermittent crack was found on the drain channel perpendicular to the drain channel to skirt weld, during an in-service inspection. In addition, a capture plates were needed over the opening which contains the tie-rod end nuts, to eliminate possible loose part hazards. Repair was done in the equipment pool.

Repair Description: The intermittent crack was determined to be a superficial and no repair was carried out. The location where the capture plates were to be installed was first ground flush. The capture plate were then welded to the steam dryer in four locations or quadrants. In each location 3 sets of 2 nuts were covered. The capture plates were 1-1/2 by 5-1/2 in. stainless steel plates 3/16 in. thick.

Depth of Repair: Not Stated

Water Conditions: Not Stated

Radiation Levels: Not stated

Total Exposure: 2.3 rem for 6 dives and 16 1/2 hours down-time, with maximum exposure to single diver 785 mr.

Materials: Type 304L S.S.

Electrodes: Not Stated

Weld Qualifications: Weld procedures were qualified in accordance with ASME Section IX specifications. Welder qualifications were performed in the 3F, 2F, 4F positions as required by ANSI/AWS D3.6. Each welder was required to perform a macroetch specimen on a mock-up on all qualified positions.

Personnel: Two diver/welders were qualified for the welding procedures, and two additional divers were utilized for grinding operations.

Equipment:
Welding Equipment: An inverter type DC power supply was used for all welding procedures. Standard weld leads and ground clamps along with a proprietary UW electrode holder were connected through a knife switch at a master control station.

Diver Equipment. Divers wore full rubber dry suits including integral feet and water-tight gloves and welding helmet. An umbilical line was used to supply breathing air and a intercom system was used for continuous communication to dive tenders. The breathing air was supplied by a main compressor and a back-up compressor.

Monitoring Equipment: Video equipment, T.V monitor and UW camera were used for recording repair procedure and for final and intermediate inspection.

Other Equipment: Water powered grinder and pneumatic chipping hammer was used to clean weld interpasses. A water vacuum (100 gal./min) was used to recover weld slag, grinding and cutting particles and remanents of waterproof electrode coatings.

Mock-up: All tests were completed on a mock-up of the actual joint configuration.

Safety Precautions: Divers were in contact at all times with the dive tenders and welding power was contacted on divers instruction only. In addition the divers wet suits were leaked tested prior to each dive.

Individual radiation was monitored as described in section 7. Real-time monitoring of selected body parts was continuously monitored due to possible high dosages. Body position was altered regularly to reduce exposure.

CASE HISTORY NO. 7

Utility: Philadelphia Electric Company, Peach Bottom Unit 3, Delta, PA - Fall 1988.

Vendor: Global Divers and Contractors, Inc. (11)

Repair: Structural damage of the steam dryer, due to a misalignment during reinstallation in the reactor, caused damage to two lower guide brackets and skirting. At the same location there was cracked welds at the base of the drain channels and damage was discovered on a alignment/seismic lug. Repair was completed in the equipment pool.

Repair Description: The cracked drain channel welds consisted of 1/8 in. (3.25 mm) 2G and 3G groove welds and 1/8 to 114 in. (3.26 to 6 mm) 3F fillet welds. The dryer skirt welds consisted of 1/4 in. (6 mm) 2G and 3G groove welds. The support ring consisted of 1 and 5/8 in. (26.4 and 16 mm) 3G groove welds. The support ring to dryer skirt consisted of 1/4 to 1 in. (6 to 25.4 mm) 2G groove welds. Cracks were first ground out using a water grinder or arc-water gouger, realigned, then rewelded. Heavily damaged areas of the skirt were completely removed and replaced.

Depth of Repair: 13 to 23 ft (4 to 6 m)

Water Conditions: Excellent visibility with water temperature between 80 and 85°F (27-29°C).

Radiation Levels: 1-3 r/h (roentgen) on contact and 300-500 mr/h at 18 in.

Total Exposure: 5.3 man-rem for all diving activities; a potential exposure savings of over 100 man-rem if repair was done in the dry.

Materials: SA240, Type 304 stainless steel.

Electrodes: E316L SMAW electrodes with proprietary water proof coating (Global).

Weld Qualifications: All of the procedure and performance qualifications were m accordance to AWS D3.6 -83, Type B welds. Twelve procedure qualifications were conducted for the 2G, 3G, 2F and 3F positions with material thickness ranging from 1/8 to 1 in. Tests welds were carried out in 33 feet of water so that a range of 10 to 66 feet (3 -20 m.) would be covered.

The ferrite number of the weld deposit was confirmed by running an undiluted weld pad and measuring with a ferritoscope. The slag was checked for halogens (especially chlorine, bromine and fluorine). The carbon content was also verified to be lower than .04%. These tests are to ensure that sites for IGSCC were not produced.

Diver/Welders (D/W) were required to take 5 separate qualification tests, to be qualified for all positions and thicknesses. The D/W were also required to train by completing a simulated repair of a mock-up. The simulation included lay-out work, template making, scribing, arc-water gouging, grinding and installation procedures, all from behind the shielding plates (18 in.). The entire mock-up procedure was timed and video taped.

Personnel: Twelve/diver welders were qualified for the welding procedures.

Equipment:
Welding Equipment: Not Stated.

Diver Equipment: Divers wore dry suits and free flowing helmets. The divers wore lead lined aprons with neck and upper arm bands.

Monitoring Equipment: Video equipment was used to record the mock-up procedures and inspections.

Other Equipment: Water powered grinders and arc-water gougers were used to prepare cracks and weld joints. C-clamps were used to position and pull together separated sections to be welded.

Mock-up: A complete mock-up including safety shields were installed in a 33 feet deep dive tank. The divers were familiarized with safety procedures and all aspects of the repair application.

Radiation Barriers and Work Platforms: A shielded work station was built to protect divers from exposure. The work station consisted of two shield blocks which consisted of 2 in. lead enclosed in 1/4 in. carbon steel (Section 3). Two other shields of same cross-section were made to slide so that specific areas could be shielded. Divers could position the sliding doors to create a low dose area (<5 mr/h).

Safety Precautions: Divers wore additional protective clothing such as lead lined aprons with neck upper arm bands and helmets lined with 1/4 in lead. The work platform limited divers access to the higher levels of radiation.

CASE HISTORY NO. 8

Utility: Three Mile Island Nuclear Power Plant, Unit 2, May 1988 through April, 1989.

Vendor: PCI Energy Services (35)

Repair: A partial fuel melt accident allowed 20,000 lbs of fuel to resolidify on the bottom of the reactor vessel. To enable refueling operations a section of the lower-core support assembly (LCSA) had to be removed to improve accessibility. Five components of the LCSA had to be penetrated: the lower-grid top rib assembly, the lower grid flow distributor plate, the grid forging, the in-core guide support plate, and the flow distributor head. Due to the radiation levels all operations were remotely operated.

Repair Description: The removal of the five components required cutting material thicknesses ranging from 2.5 to 6.4 cm. (1 to 2.5 in.) in horizontal, vertical and angular cutting positions. A five axis manipulator was developed and modified to carry plasma torches, water jet cutting nozzles and rotary grinders. Four plasma torches were developed for various cutting angles and sizes.

Remote cutting operations were staged in a sequence which created access to the proceeding area. The cutting progress resulted in the following sequence:

- Opening in lower-grid top rib assembly was enlarged using 90° plasma torch.
- Lower-grid distributor plate was removed with a 90° plasma torch.
- In the lower-grid rib-forging area, 28 of the 48 support posts were removed to access the forging. Cuts were made with a 90° plasma torch attached to a Z-axis manipulator. In addition, 38 of the 52 in-core instrument guide tubes were cut off, using a rotational sweep cutting motion with a 90° plasma torch, allowing greater accessibility in removing the forging.
- The lower-grid rib-forging was cut and removed in four sections.
- The instrumentation guide tubes were again cut down to a level just above the in-core guide support plate, utilizing a mechanical abrasive saw.
- The in-core guide support plate was unbolted using a long handled torque tool and cut up into four section with a 180° plasma torch.

After the surface of the flow distributor plate was defueled, it was cut up into 25 sections with the plasma torch.

Final cutting operation utilized the 180° plasma torch attached to a 90 ° extension, to cut out the baffle plates to access solidified fuel between the baffles and the core barrel.

Depth of Repair: Up to 35 feet.

Water Conditions: Borated to approximately 5000 ppm and buffered with 1200 ppm sodium hydroxide producing a 7.5 pH level.

Radiation Levels: 1000 R/hour on contact.

Total Exposure: All activities were remotely operated.

Materials: Not Stated.

Equipment:
Monitoring Equipment: Underwater video cameras were utilized for monitoring cutting progress and material handling.

Mock up: A complete full size mock up was used for designing cutting equipment, evaluating cutting parameters and development of sequence of operations.

CASE HISTORY NO. 9

Utility: Almaraz 1 & 2 (W PWR), Central Nuclear de Almaraz, Caceres, Spain, January 1992.

Vendor: Diving Services, Inc. via Equipos Nucleares, S.A.

Repair: During fuel pool reracking operations, vertical fuel pool liner panels received damage. The liner was breeched and through-wall leaks occurred in at least two locations. Although not leaking, three other areas of minor damage were also scheduled for repair. Damaged areas in the 2 mm (approximately 0.080 in.) liner panels required installation of similar thickness patch plates.

Repair Description: Patch repair plates (2 mm thick) were sized to completely cover damaged areas and were attached with single pass lap-type configuration fillet welds. Repair plates typically averaged 4 x 4 to 6 x 6 in. square. Close fit-up of the patch material to the existing liner panels was critical. Fit-up tacks were applied on approximate 2-in. centers to minimize movement during welding.

Depth of Repair: Repairs areas ranged from 10 to 30 feet.

Water Conditions: Typical PWR borated water @ 2000 ppm.

Radiation Levels: 50 to 100 MR per hour (general area).

Total Exposure: Not Available.

Materials: SA 240, Type 304L

Electrodes: 3/32" Avesta P5 VDX, E309LMoSi-16, Polyurethane Spar Varnish Waterproofing applied with EPRI Developed Pressure Treatment Method

Weld Qualifications: Welding procedure and welder performance qualifications were conducted in accordance with ASME Section IX. Test coupons simulating the lap-type configuration fillet welds joining the 2 mm material were conducted in the 2F, 3F, and 4F positions.

Personnel: Two (2) diver/welders were qualified for welding. One diver/mechanic was used for positioning and equipment set-ups. One quality control plus one health physics individual were also part of the five person crew.

Equipment:

Welding Equipment: A POWCON, Model 300ST, inverter direct current power source provided welding current to standard welding leads, safety knife switch and a standard underwater SMAW electrode holder.

Diving Equipment: Divers wore full rubber dry suits with integral feet and water-tight gloves and helmet. Breathing air and intercom communications were supplied to the diver via a standard umbilical cord arrangement. Breathing air was supplied from plant sources with back-up from compressed air bottles.

Monitoring Equipment: General surveillance and visual inspections were accomplished by electronic video means.

Other Equipment: Not Applicable.

Mock-up: Mock-up assemblies simulating the single and multiple lap weld configurations were also required for each diver/welder.

Radiation Barriers and Work Platforms: Scaffold type platforms designed to provide access at each repair elevation were provided by plant personnel.

Safety Precautions: Personnel radiation exposure was typically monitored via 12 direct reading dosimeters plus 12 thermoluninescent dosimeters (TLDs), strategically located on the head, upper torso, groin, and extremities.

CASE HISTORY NO. 10

Utility: Brunswick 2, Carolina Power & Light Co., Fall 1991

Vendor: General Electric Company with Brand Utility Services (formerly Nuclear Underwater Construction) as their subcontractor (20)

Repair Through-wall cracks were observed m the type 316L stainless steel core spray tee box components inside the reactor vessel. Reinforcement of the assembly by welding stainless steel gusset plates to the tee box was determined to be an acceptable permanent repair method. This was the first safety related underwater welding application completed m the industry. Repair in a dry environment would have required partial draining of the vessel and would have resulted in high radiation doses for the repair and supervisory personnel.

Repair Description: ASME SA-240, Type 316L stainless steel gusset plates measuring 3/8 in. thick, 6 in. high, and 24 in. long were attached to the core spray tee box with 1/4 in. fillet welds. Total weld length per gusset was approximately 52 in. Two gussets were attached, 140 degrees apart (top and bottom), on the tee box. Gussets were initially checked for alignment and were remachined on site to match the existing configuration. The gussets were initially tack welded m place and then welded out complete.

Depth of Repair: 45 feet.

Water Conditions: Excellent visibility. Welder could be observed clearly through sight window on surface.

Radiation Levels: Teebox was 2 to 3 R/hr on contact. Outside the shielded work platform base was 5 R/hr. Inside work platform, radiation level on floor ranged from 7 to 60 mR/hr.

Total Exposure: Total whole body dose for 9 welders was 9 person-Rem. Total number of dives was 33, and the average dose per dive was 272 mrem. The maximum dose for one dive was 1.4 rem.

Electrodes: E309L-16 SMAW, 3/32 in. diameter with varnish waterproof coating.

Weld Qualifications: All procedure and performance qualifications were conducted in accordance with ASME Section IX (for testing methods) and AWS D3.6-89 (for essential and nonessential variables). Since this welding was for stainless steel, some of the essential variables related to carbon steel were considered not applicable. Qualification depth requirements from AWS D3.6-89 were used. Groove weld qualifications were used for procedure qualification, and fillet weld qualifications were used for welder performance qualifications in each position required underwater.

Personnel: Nine divers were used in an around the clock operation, along with supervisory personnel.

Equipment:

Welding Equipment: Bernard short stud electrode holders were used with 1/0 cables. Miller inverter type welding power sources were used, and a mechanical knife switch was used at the surface to open/close the welding circuit when requested by the welder on the radio.

Diving Equipment: Viking Dry Suit with hard hat dive helmet with integral flip-up welding lens and two way radio system. Specialized anti-C diving gloves were also used.

Monitoring Equipment: Teledose remote monitoring systems were used for continuous monitoring by surface personnel. A total of 9 TLDs were used on each diver, including extremities.

Other Equipment: Pneumatic grinders with hardened steel burr bits were used for contouring welds.

Radiation Barriers and Work Platform: A stainless steel work platform with a lead lined floor was custom built for this project, and it was suspended from the refuel floor crane. Additional shield blankets were draped over the sides of the platform and other components. During operations, the platform remained stationary, and the divers swam to and from it to the surface, with the aid of a fixed lanyard.

Safety Precautions: ALARA guidelines were in effect. Constant communication was maintained with the divers, and additional divers were available for support at all times. Area video cameras were also used to monitor the diving activities.

Appendix VIII

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