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TORPEDO PROPULSION TEST AND DEVELOPMENT CAPABILITIES AT  
NUSC (NAVAL UNDERWATER SYSTEMS CENTER) (U) NAVAL  
UNDERWATER SYSTEMS CENTER NEMPORT RI 1984 NUSC-TD-6288

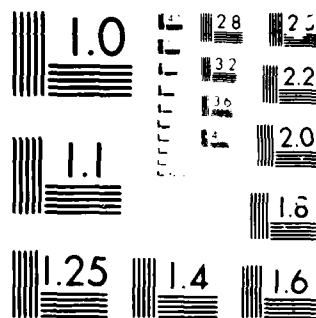
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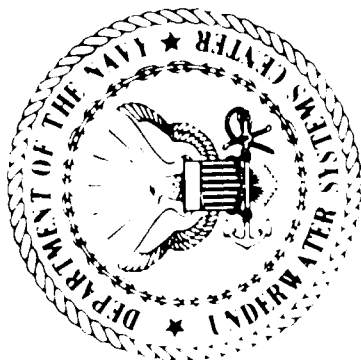


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# Torpedo Propulsion Test & Development Capabilities At NUSC



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"OUR REASON FOR BEING IS THE FLEET WE SERVE"

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NAVAL UNDERWATER SYSTEMS CENTER  
NEWPORT LABORATORY, NEWPORT, RHODE ISLAND

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# **Torpedo Propulsion Test & Development Capabilities At NUSC**

Naval Underwater Systems Center  
Technical Document 6208

Reviewed and Approved:  
1 February 1984

*J. W. Ailes, IV*

J. W. Ailes, IV  
Captain, U. S. Navy  
Commanding Officer



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## **Table of Contents**

|                                                                   |    |
|-------------------------------------------------------------------|----|
| <b>Introduction</b> .....                                         | 1  |
| Purpose .....                                                     | 1  |
| Torpedo Propulsion Expertise at NUSC .....                        | 1  |
| <b>Propulsion Test Facility Components</b> .....                  | 3  |
| Instrumentation and Control Center .....                          | 4  |
| Component Test Facility .....                                     | 6  |
| Systems Depth Test Facility .....                                 | 10 |
| Steam Generation Facility .....                                   | 14 |
| Thermal Propulsion Support Laboratory .....                       | 16 |
| Battery Test Facility .....                                       | 20 |
| Materials and Chemistry Laboratory .....                          | 22 |
| <b>Summary of Propulsion Test Facility<br/>Capabilities</b> ..... | 24 |
| <b>Propulsion Test Facility Personnel<br/>and Services</b> .....  | 26 |
| Staffing .....                                                    | 26 |
| Other Services and Expertise Available .....                      | 26 |

# Introduction

## Purpose

The purpose of this document is to describe the extensive capabilities of the Naval Underwater Systems Center (NUSC) in the area of torpedo propulsion system testing and development. The document provides a description of the operation and functional capabilities of NUSC's Propulsion Test Facility, together with a summary of the technical expertise and services available from NUSC personnel who manage, direct, and support the facility.

## Torpedo Propulsion Expertise at NUSC

NUSC is one of eight Navy laboratories under management of the Chief of Naval Material. NUSC has particular responsibility for research, development, test, and evaluation of submarine and surface-launched tactical weapons and sensor systems.

Research and development of underwater weapons is the principal responsibility of NUSC's Weapon Systems Department. As one part of this broad responsibility, the department's Torpedo Acquisition Division provides the technical expertise necessary to support test and development of torpedo subsystems, including power and propulsion components.

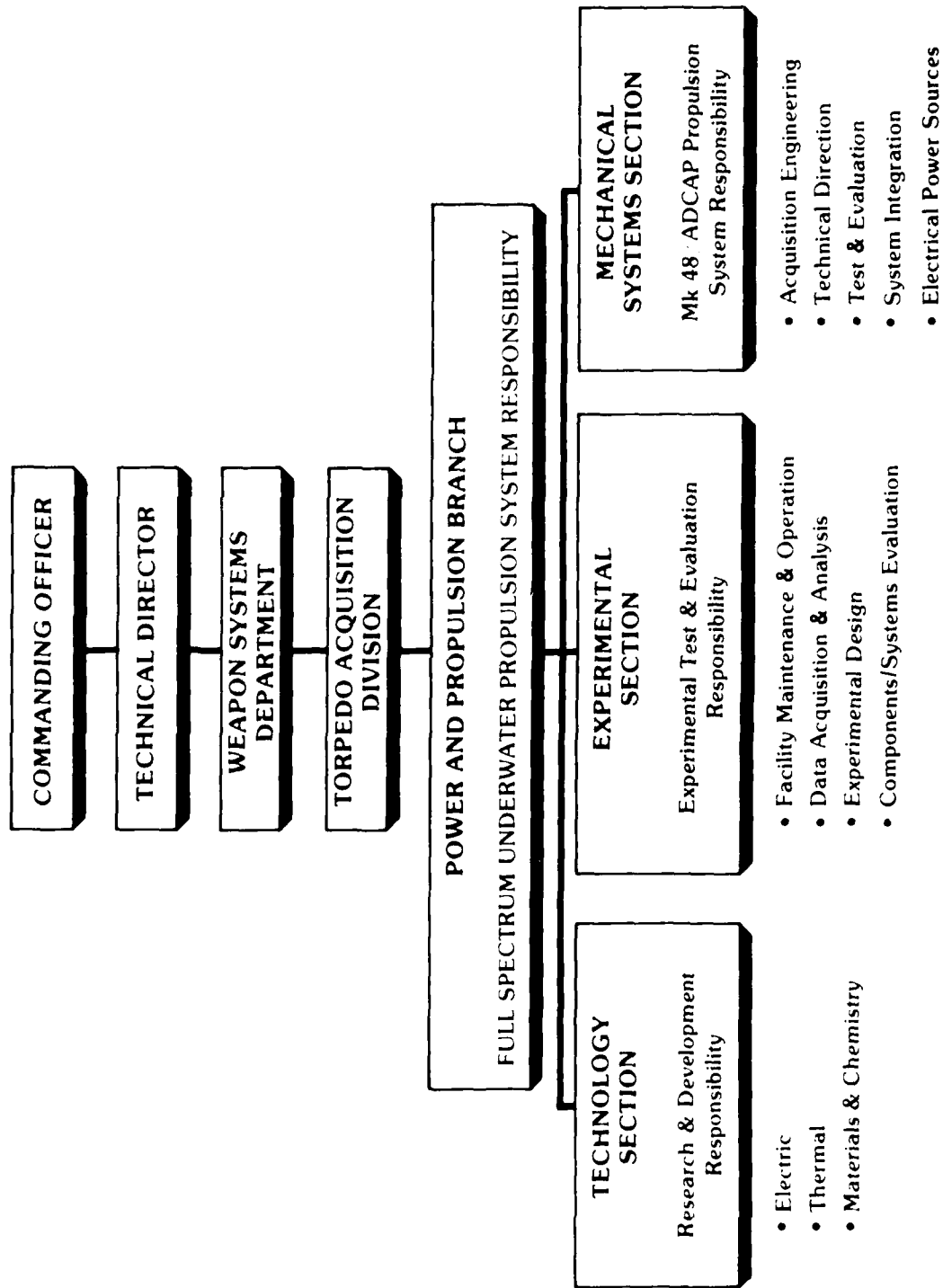
Support of underwater propulsion system development and acquisition (from the exploratory development phase through the in-service phase) is the mission of NUSC's Power and Propulsion Branch. To provide a full spectrum of underwater propulsion system support services, this branch:

- Manages and directs the Center's Propulsion Test Facility
- Conducts independent research and exploratory development with industrial, foreign, and other DOD laboratories
- Maintains a state-of-the-art position in the development of energy conversion technologies
- Conducts exploratory and advanced development of open and closed-cycle thermal and electric propulsion systems
- Supports in-service engineering groups on propulsion system problems

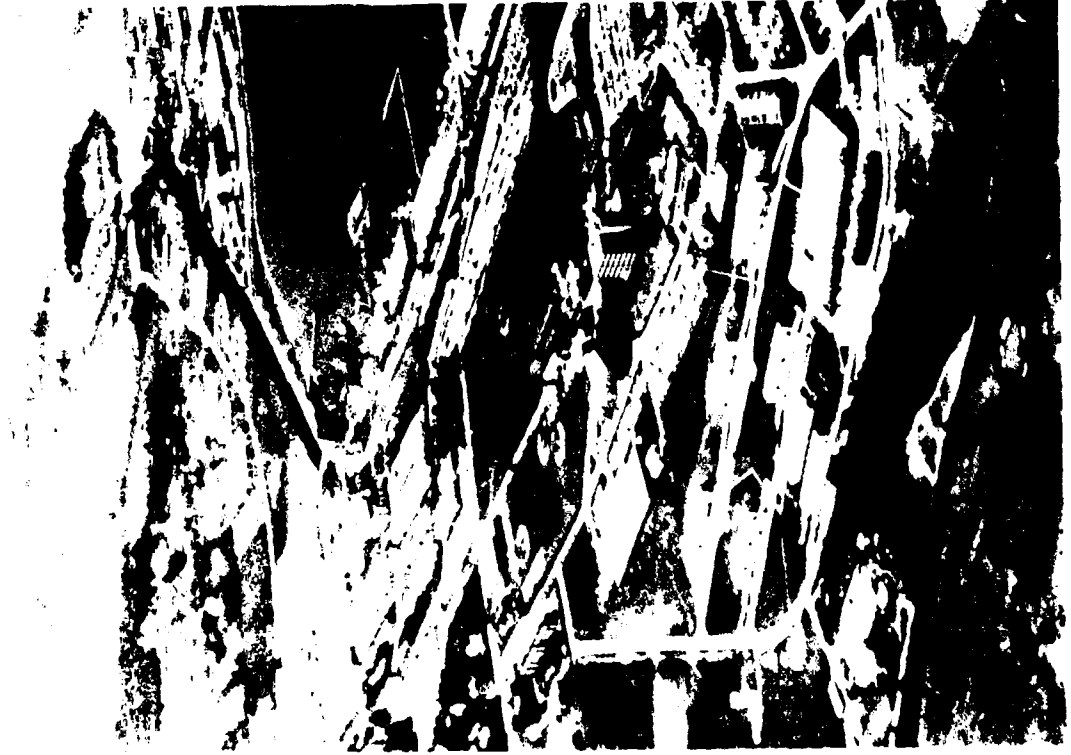
Because of its central position between the RDT&E community and the fleet, NUSC's Power and Propulsion Branch has a clear understanding of the Navy's projected propulsion system requirements. This understanding has played an important role in the success of both current and past anti-submarine and anti-ship weapon propulsion systems.

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# Organization of NUSC's Power and Propulsion Branch



# Propulsion Test Facility Components

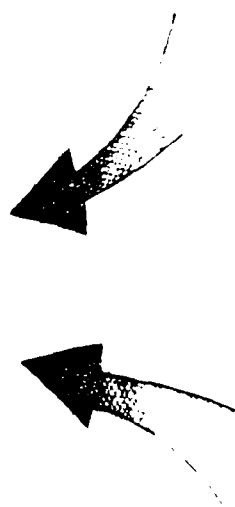
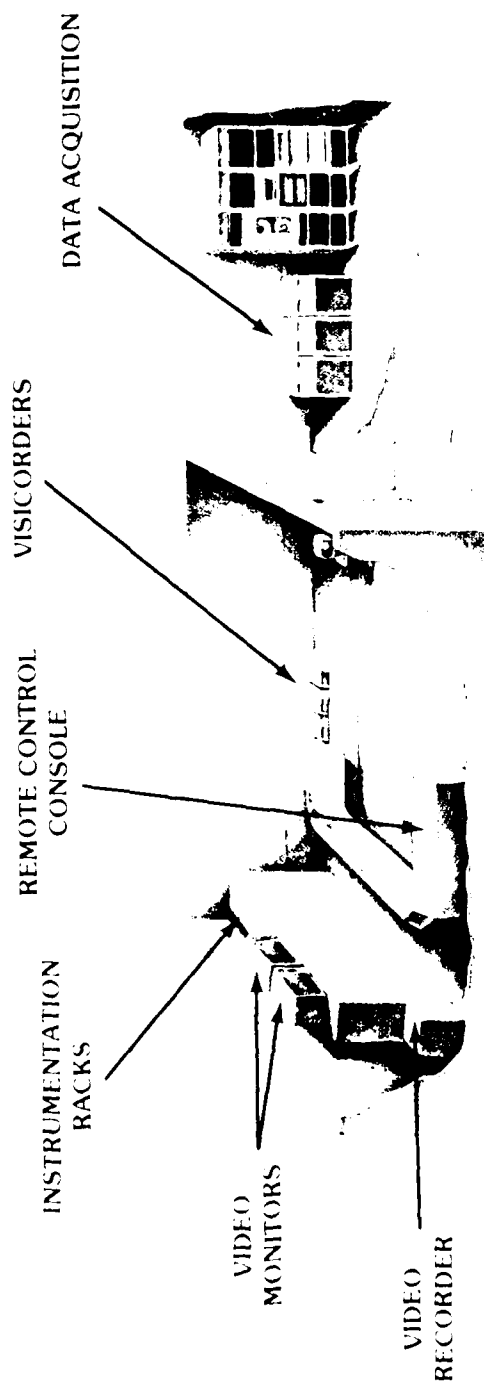


The Propulsion Test Facility at NUSC comprises a multi-component complex of test areas and laboratories. These include:

- Instrumentation and Control Center
- Component Test Facility
- Systems Depth Test Facility
- Steam Generation Facility
- Thermal Propulsion Support Laboratory
- Battery Test Facility
- Materials and Chemistry Laboratory

A description of each of these components is provided on the following pages.

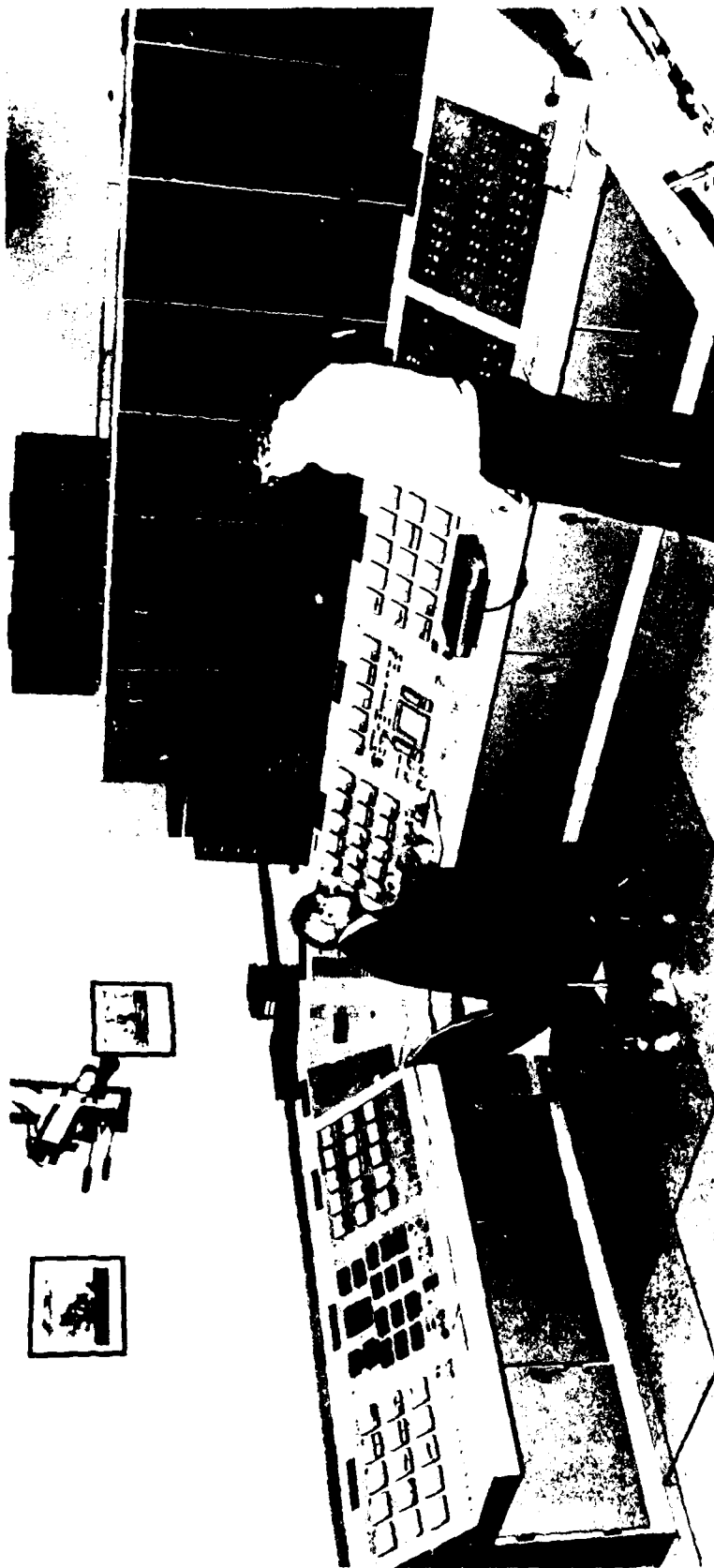
# Instrumentation and Control Center



COMPONENT TEST FACILITY

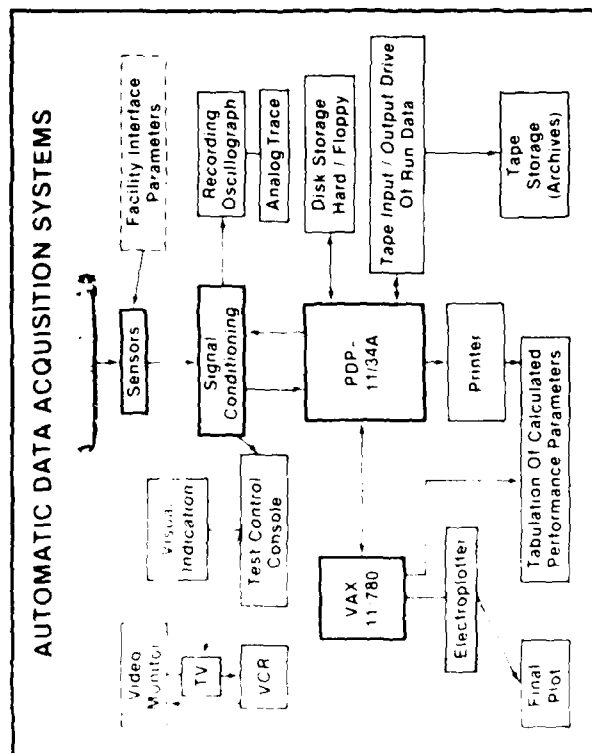


SYSTEMS DEPTH TEST FACILITY

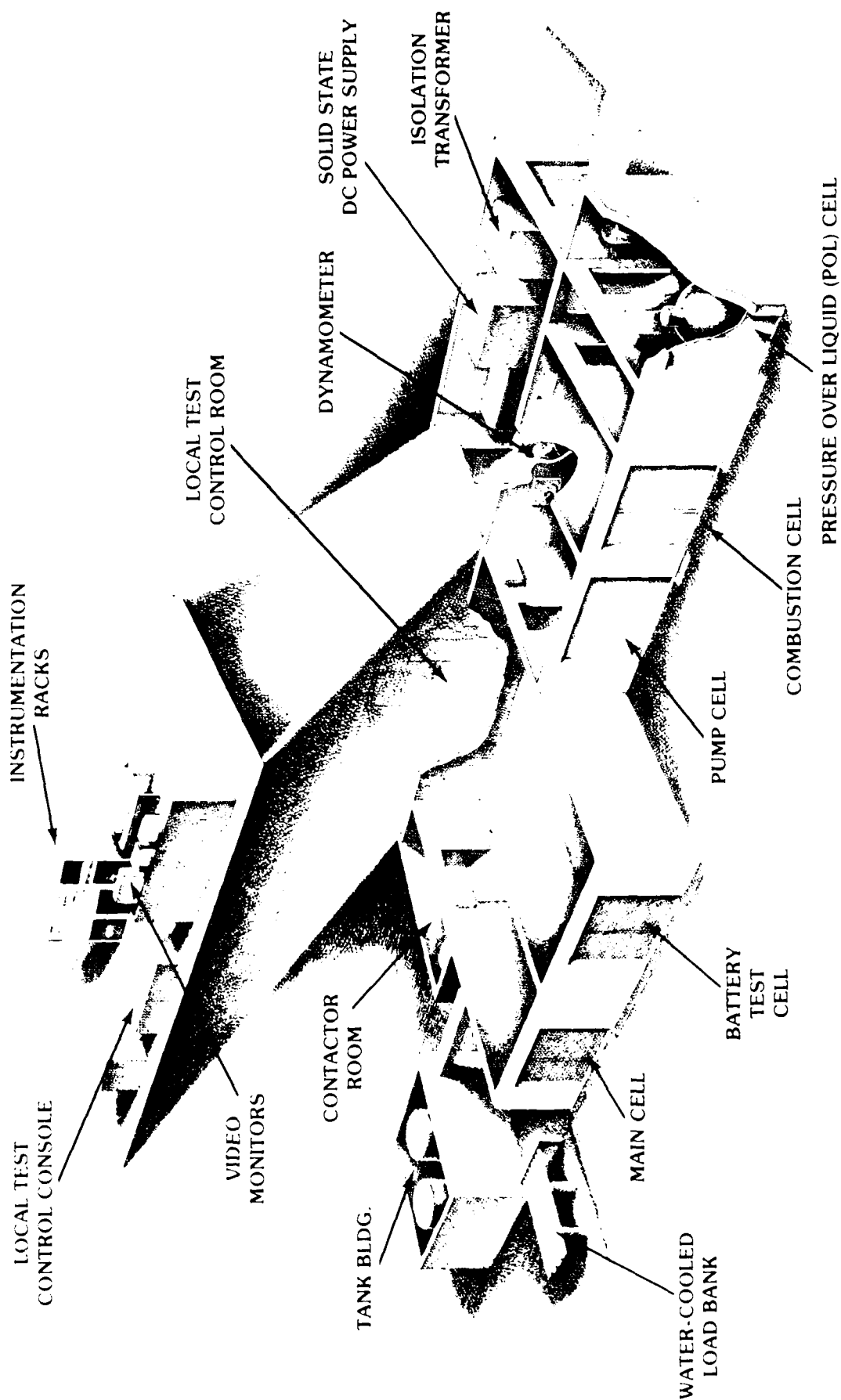


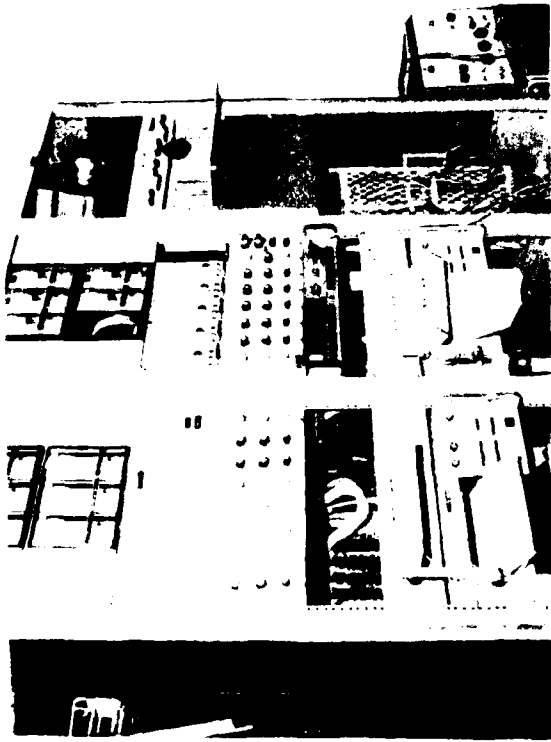
Control Room Consoles for Remote Control of Test Items and Facility Interfaces in Remote Test Cells

The Instrumentation and Control Center contains test equipment used for remotely controlling, monitoring, and collecting data on tests conducted in the Systems Depth Test Facility and Component Test Facility. The remote control feature not only affords protection during the testing of hazardous items, but also permits centralization of the modern signal processing and data collection system shown in the diagram at the left. The output of test sampling sensors is shown on real-time meters on the control room consoles and is captured by multi-channel analog recorders and a general-purpose computer. Video cameras simultaneously pick up the displays of selected consoles and voice communications for recording by a video cassette recorder (VCR) and remote display on TV monitors. Available software enables test directors to isolate and store discrete samples for ready recall on a printer or video monitor. Data can also be transferred electronically to other computers at NUSC for data analysis. The control center uses an expanded PDP-11/34A computer for data recording, communication, and processing.



# Component Test Facility





*Control and Signal Conditioning Data Acquisition Center*

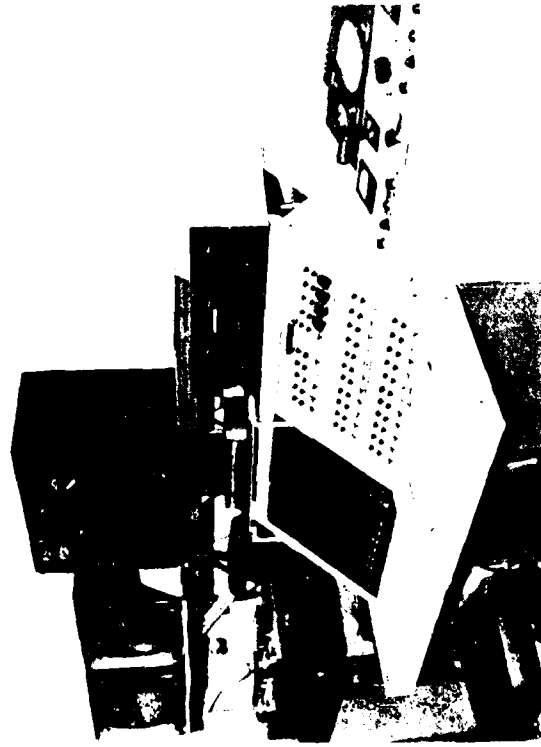
The Component Test Facility consists of four general-purpose test cells specially configured for containment of detonation, explosive, fire, toxicity, and fragmentation hazards. The cells are also provided with high-, medium-, and low-pressure air service, fresh and salt water, and high-capacity drain and ventilation systems. Propellant and oxidizer tanks with remotely controlled pressurizing systems, various electric power supplies, switching gear, and resistive load banks are among the available equipment.

One of the test cells is served by a 125-hp, 6000-rpm motorizing dynamometer that can be controlled either remotely or locally.

A control room is provided for local control and readout of cell instrumentation if remote control from the Instrumentation and Control Center is unnecessary.

A small annex building houses a 1000-gallon seawater delivery system, a 1000-gallon calorimeter, and a temperature control system for conditioning the seawater or calorimeter.

The facility is currently used for testing torpedo components, including pumps, combustors, engines, batteries, motors, speed reducers, and valves. It has been used for complete system tests, including the NUSCAL battery's technology assessment phase, and as a government-furnished service for the advanced development phase of the ALWT's (advanced lightweight torpedo) electric propulsion system.



*Control Room Showing VCRs, Real-Time Display Panel, Test Item and Facility Control Consoles and Motoring Dynamometer Controller*

## Component Test Facility (Cont'd)

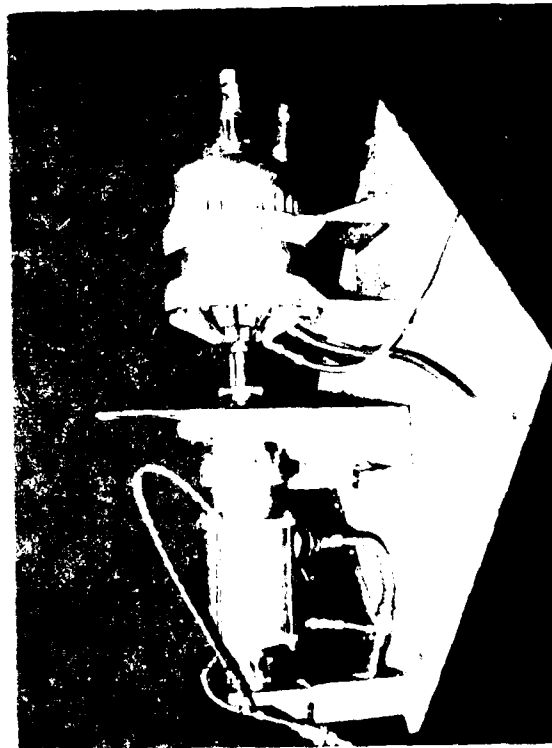
Rated for 125 hp and 6000 rpm, the motoring dynamometer shown at the right allows the testing to capacity of most torpedo propulsion system components and pumps. Tests can be controlled either from the local control room or remotely from the control center.

Depicted below is the fixture specially fabricated for run testing of the NUSCAL pile battery in a full-scale, in-water configuration. For testing, the battery is inserted in the aperture shown.

At lower right, the REI-11 Wankel expander is driven by high-pressure heated air to check lubrication and general operation before it is transferred to the noise test cell in the Systems Depth Test Facility for testing with high-energy steam.



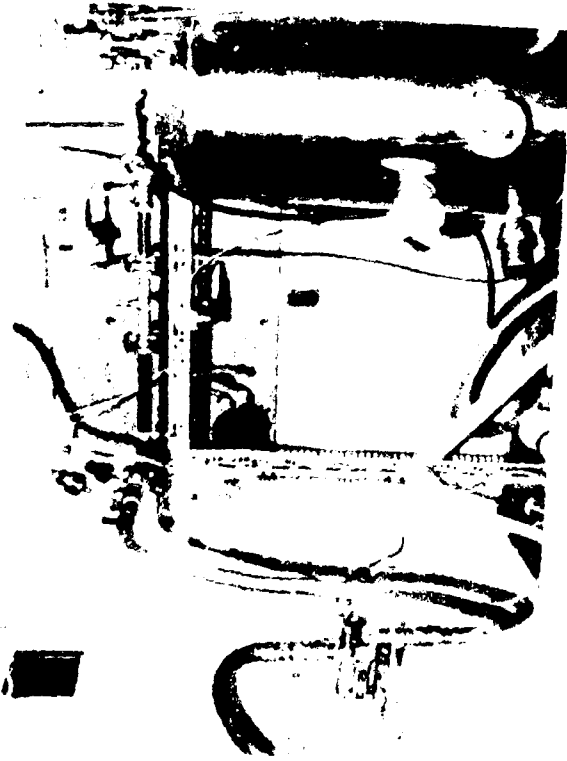
*Motoring Dynamometer. Separated from the test cell by an explosion-proof wall, this direct current device may operate as an electric motor or as a generator*



*Wankel Expander High-Pressure Air Test Setup*



*NUSCAL Brassboard Test Stand*



*Mk 48 Coolant Pump Setup*

The cells of the Component Test Facility are used to test equipment of widely dissimilar capacities and servicing requirements. Shown at the left here is a coolant pump for the Mk 48 torpedo engine. It is driven by the motoring dynamometer on the other side of the test cell wall. The test fluid is circulated through an elaborate test stand to provide a fluid load with appropriate sensors and controls.

In the lower left photograph, the 500-hp MASTOR turbine system, designed for open-cycle or closed-cycle operation, is driven with high-pressure air to check the reduction gear train and accessory drive system.

Shown at the lower right is a complex breadboard setup created for the NUSCAL battery under load. In this test, calorimeter conditioned water and electrolyte were provided to the battery to duplicate the environmental conditions in which the energy system must operate.

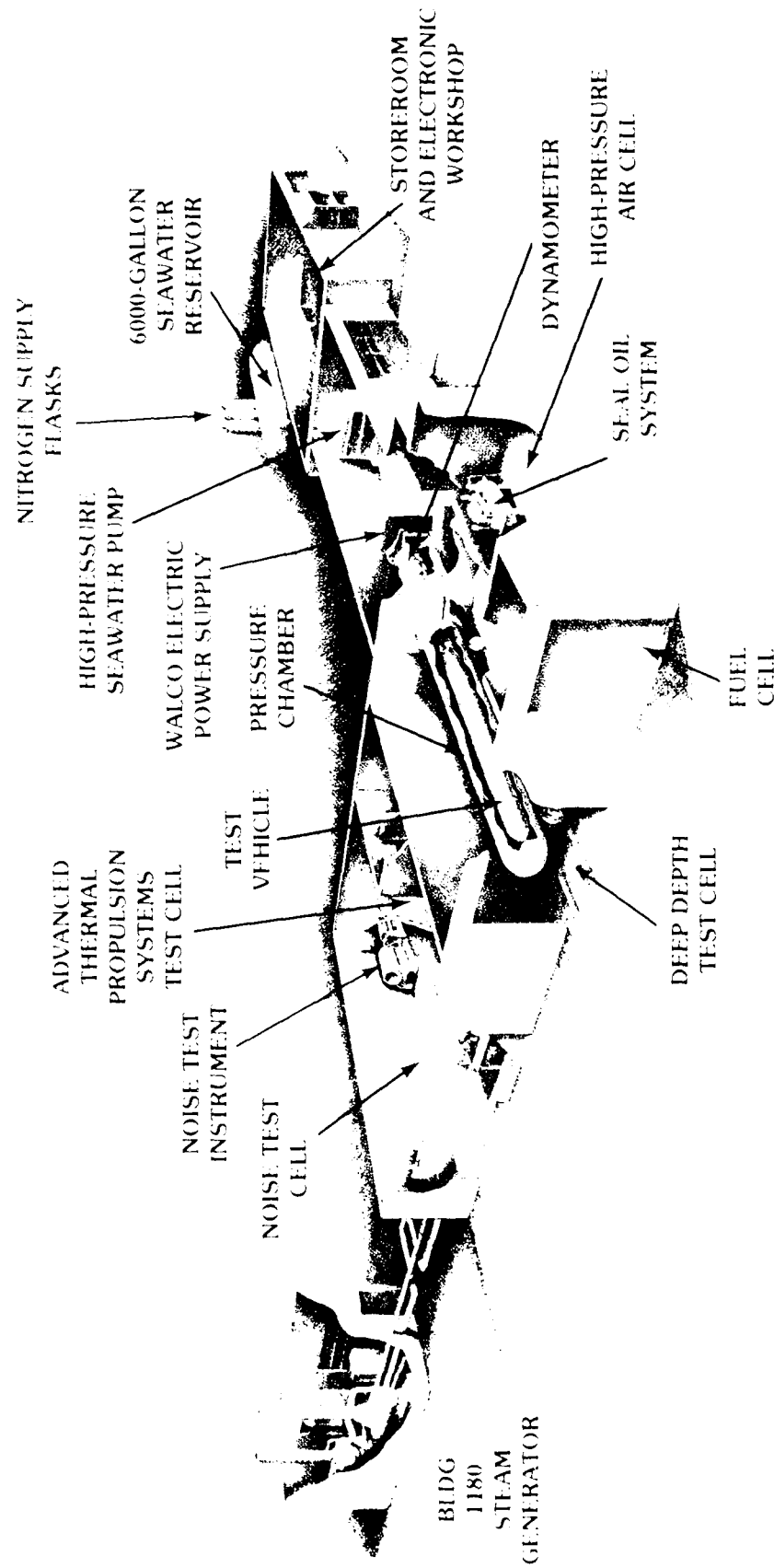


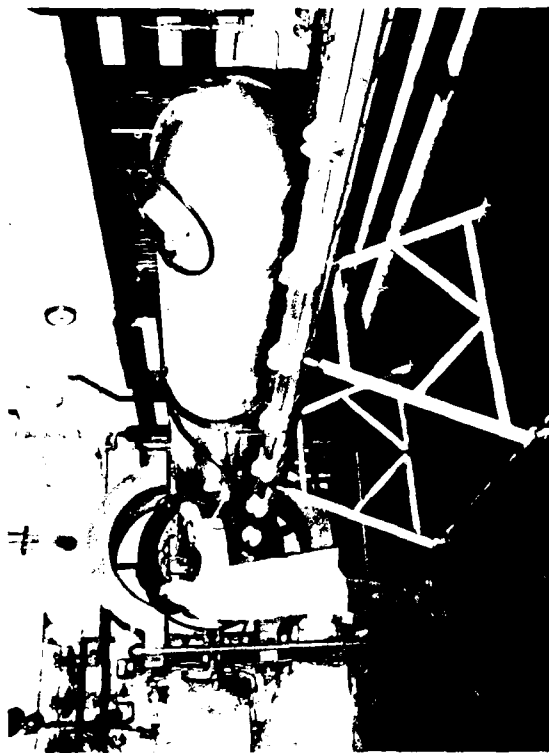
*MASTOR Engine Spin Test Using High-Pressure Air as an Energy Source*



*Breadboard Test Setup for ALWT Advanced Development Phase Aluminum-Silver Oxide Battery*

# Systems Depth Test Facility





*Technician Preparing Mk 48 Torpedo in Deep Depth Test Cell*

The Systems Depth Test Facility houses two special-purpose test cells and associated equipment. The deep depth test cell is designed to accommodate a full-scale propulsion system for a heavyweight torpedo, target, or similar submersible vehicle to a simulated depth of 5600 feet. It is the only facility in the United States capable of running a full-scale torpedo to this depth. The test cell is supported by a pressure vessel mounted on rails, a water brake dynamometer, a seawater supply, and a high-pressure pump.

The dynamometer and depth pressure controlled system are remotely operated from the control center. Entire Mk 48 torpedo and Mk 48 ADCAP propulsion systems containing fuel tankage, engine section, and tailcone section are routinely tested in this facility. Remote fuel storage tanks for thermal engines and a controlled electric power source are available for testing full-scale thermal and electric propulsion systems. The test cell is constructed for the controlled containment of detonation, explosion, fire, toxicity, and fragmentation hazards.

The second test area within the facility is the noise test cell, which contains equipment designed specifically for the conduct of noise and vibration measurements of propulsion systems or components under actual operating conditions. The noise test instrument is a specially designed fixture for the test item with a noise isolation coupling to a counterrotating dynamometer. The test fixture is sized for ALWT systems. Service systems include local and remote instrumentation, a high-pressure steam supply, an electric power supply, and a pressurized tankage system. The cell has been used for testing Mk 48 torpedo engines, the Wankel expander, the gear train for the quiet torpedo test vehicle, and the Mk 45 motor for the ADMATT target.

Steam (at temperatures up to 1300°F and pressures to 2000 psig) for the noise test cell is generated in an adjacent building containing a high-pressure single-pass boiler and superheater installed expressly for this type of research. Electric power for the test cell is supplied by a 500-volt, 650-amp, solid-state power supply.



*Noise Test Cell with Counterrotating Dynamometer Coupled to an Electric Propulsion Motor in a Propulsion System Test*

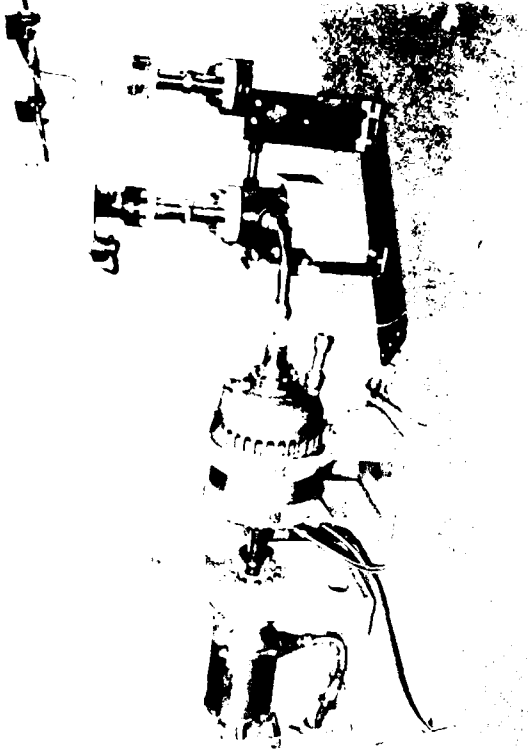
## Systems Depth Test Facility (Cont'd)

Features of the Systems Depth Test Facility shown here include:

At right, the Wankel RE1-11 expander is driven with steam, using remotely controlled steam throttling and stop valves. The setup is shown in the facility's noise test cell.

In bottom left photograph, a technician installs a tachometer on one of two Clayton water brake dynamometers for the Systems Depth Test Facility

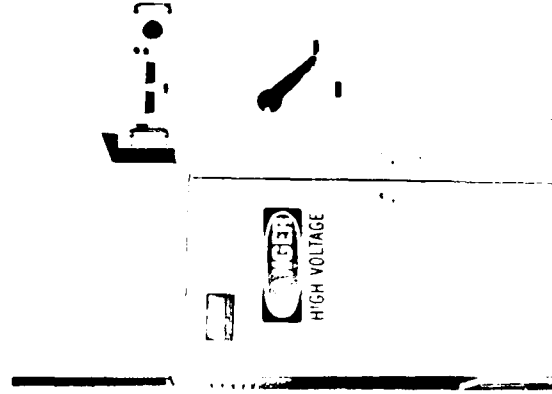
At bottom right, power supply cabinet contains a full-wave rectifier and switching gear for supplying remote control dc power to test items in the cells.



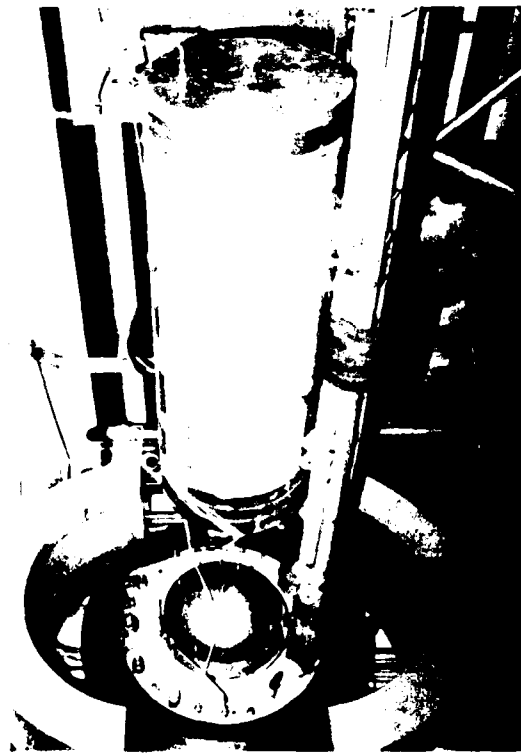
*Wankel Expander Test Setup Using High-Pressure Steam as an Energy Source*



*Water Brake Dynamometer for Deep Depth Test Cell*



*Direct Current Supply Controller for Torpedo Motor*

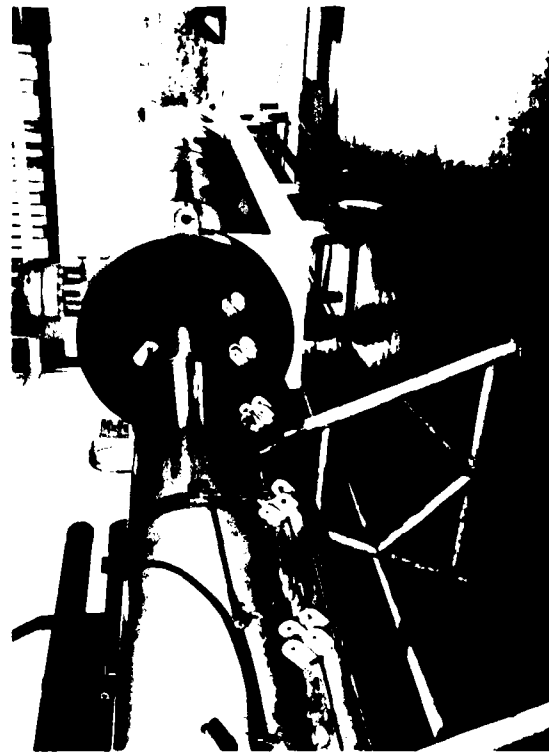


Mk 48 Torpedo Warhead Section Set Up for Depth Testing

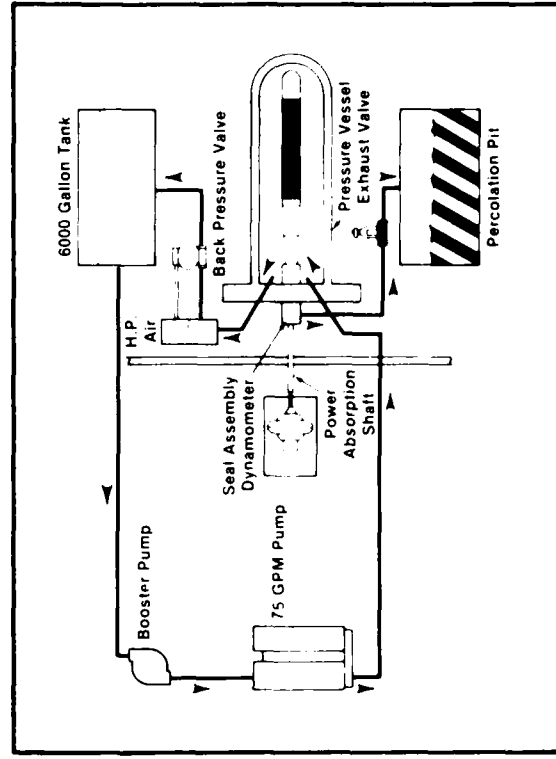
At left, the warhead section of a Mk 48 torpedo is shown prior to placement in the deep depth test cell's pressure vessel for hydrostatic pressure testing. Instrumentation includes strain gauges to monitor hull deformation and stress during testing.

At bottom left, a Mk 48 torpedo is being prepared for depth testing in the pressure vessel. The vessel's rail mounts facilitate its placement around and withdrawal from the weapon. The A-frames are removed once the pressure vessel assumes support of the torpedo and supporting tray.

Bottom right shows a simplified schematic of the components in the deep depth test cell. The cell's configuration permits full-power testing of full-scale torpedoes having either open-cycle or closed-cycle propulsion systems to a simulated depth of 5600 feet. The depth, exhaust, and power absorption at all speeds can be controlled independently from the control center.

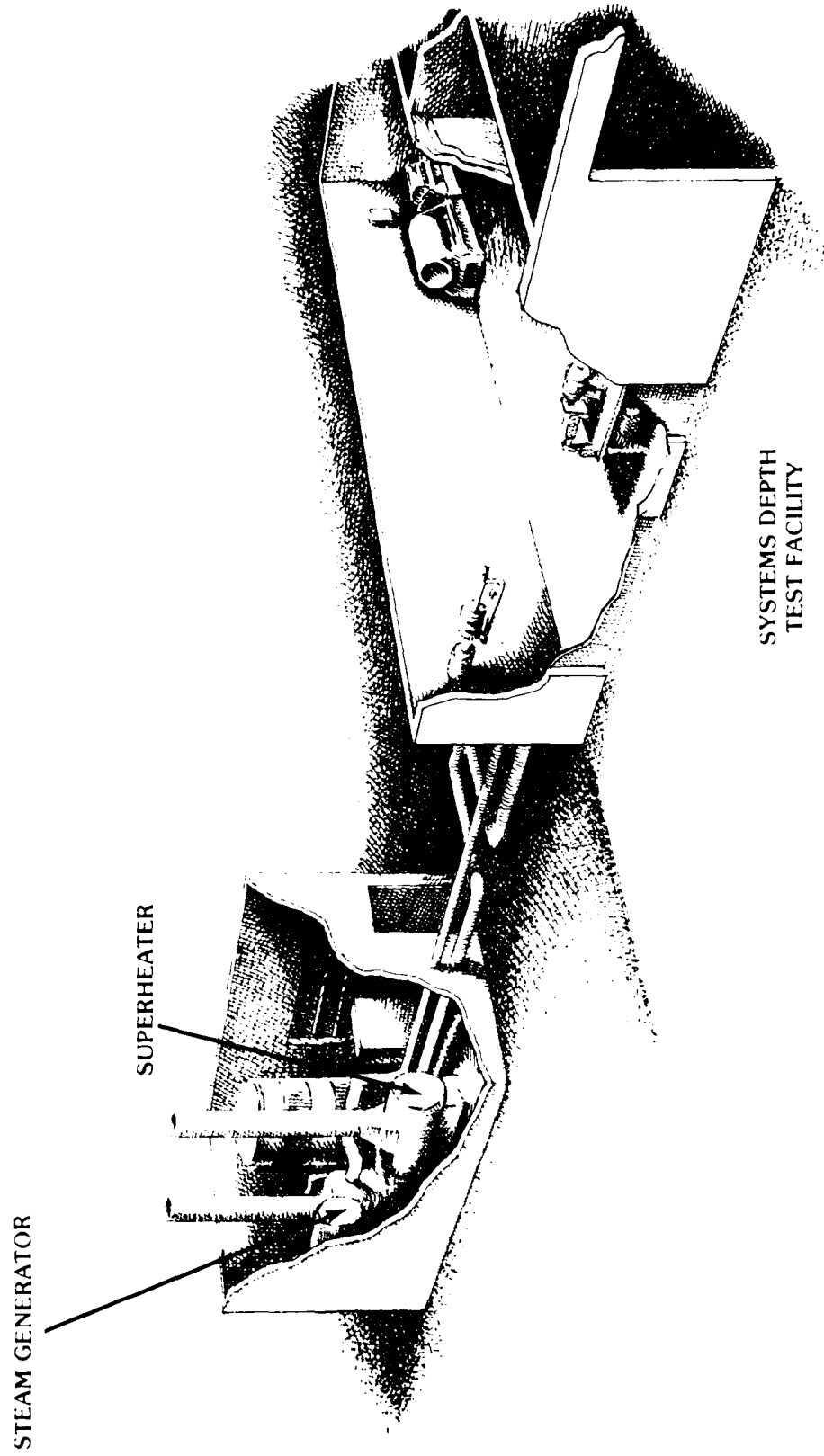


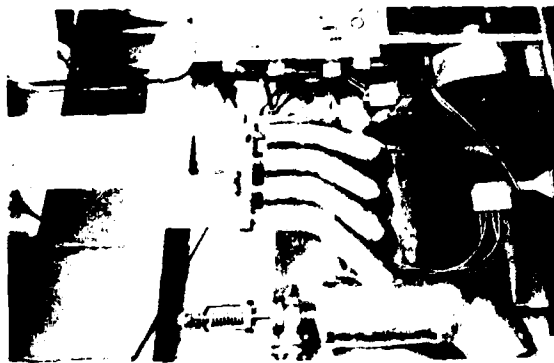
Mk 48 Torpedo Being Prepared for Depth Testing



Deep Depth Test Cell

# Steam Generation Facility

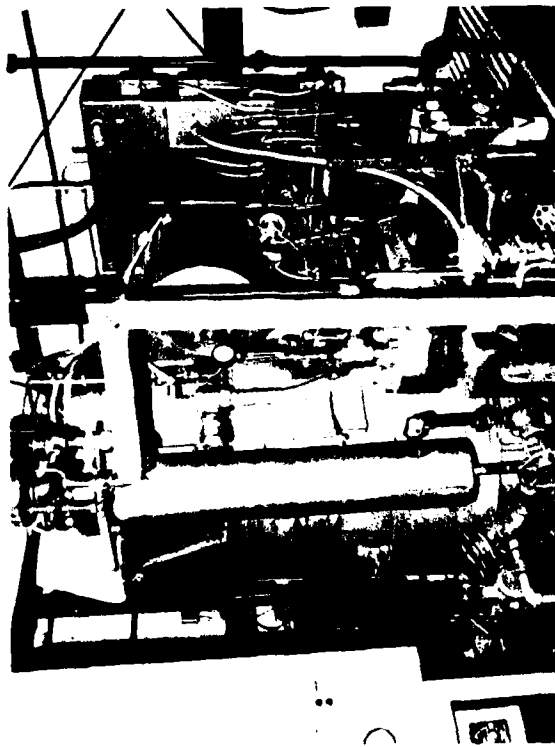




Steam Generator



Distilling Plant, Feed Water Storage Tank



Boiler

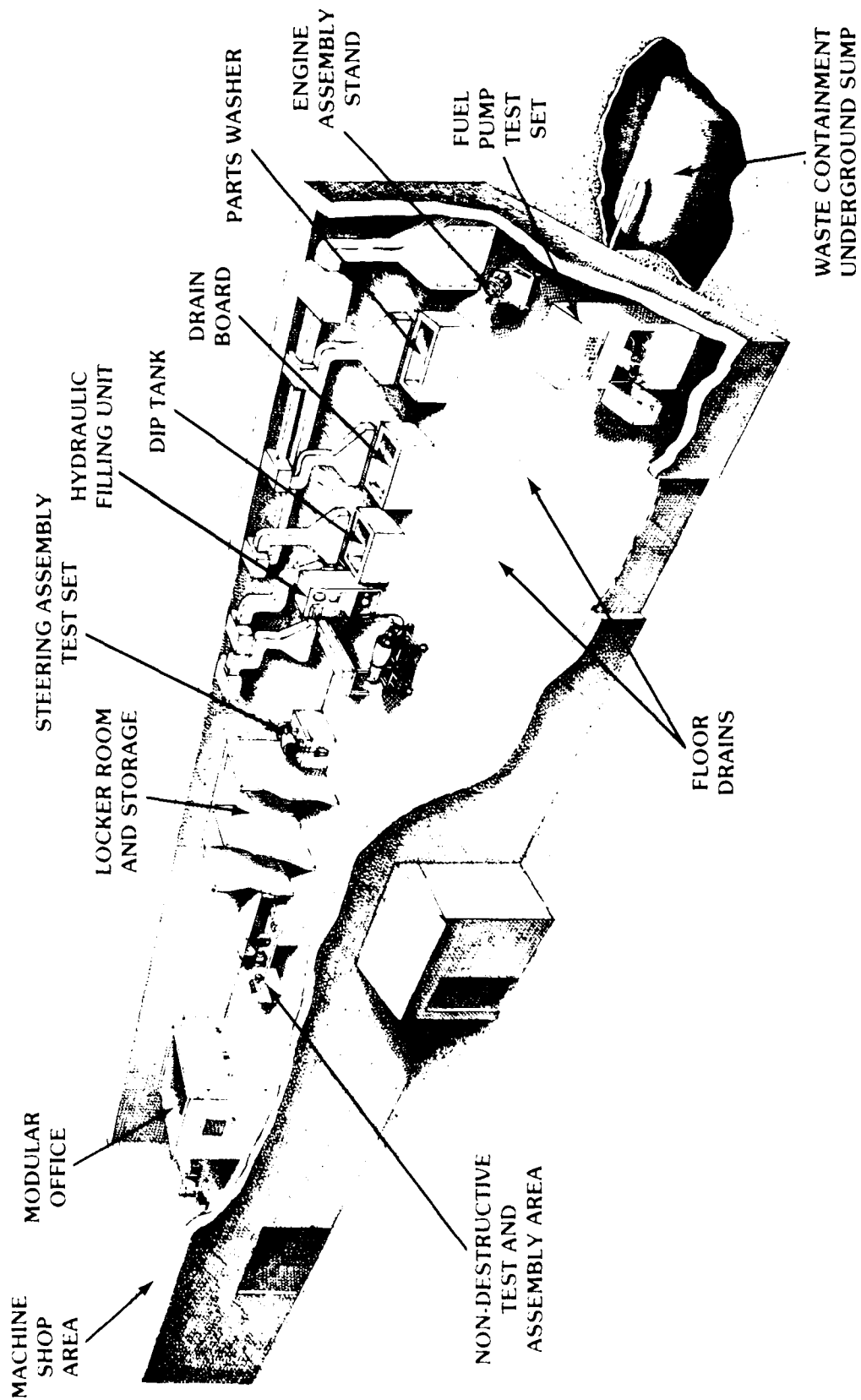
The Steam Generation Facility is located adjacent to the noise test cell in the Systems Depth Test Facility. It contains a complete steam generating plant configured to provide high-temperature and high-pressure steam at a rate of 6000 lb/hr.

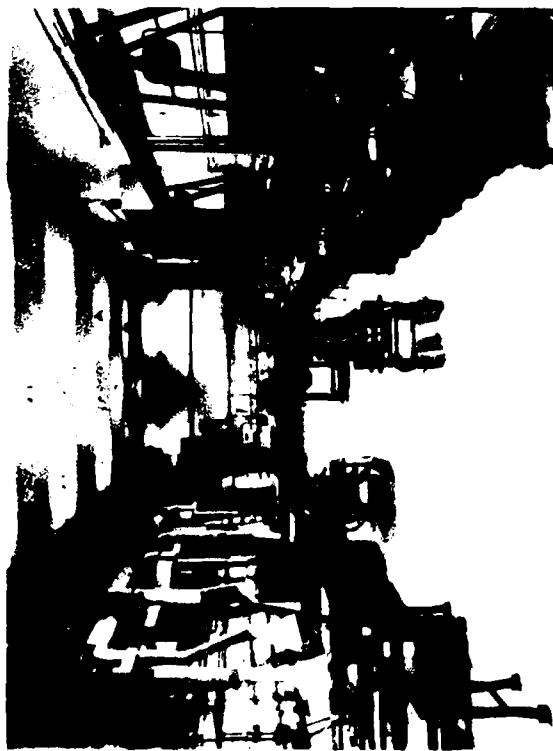
The major components contained within this facility are a single-pass boiler that produces 200 to 2000 psig saturated steam and a superheater that superheats the steam from the boiler to temperatures up to 1300°F. A distilling unit with a 1300-gallon storage system is also located within the facility. Boiler water treatment for pH control and oxygen removal is available. Either locally or remotely controlled, the entire system is ASME boiler code approved and maintained.

This steam system has been a major contributor to the development of thermal expanders such as the Wankel RE1-11 and MASTOR engines. It can be used to develop condensers and heat exchangers as well.

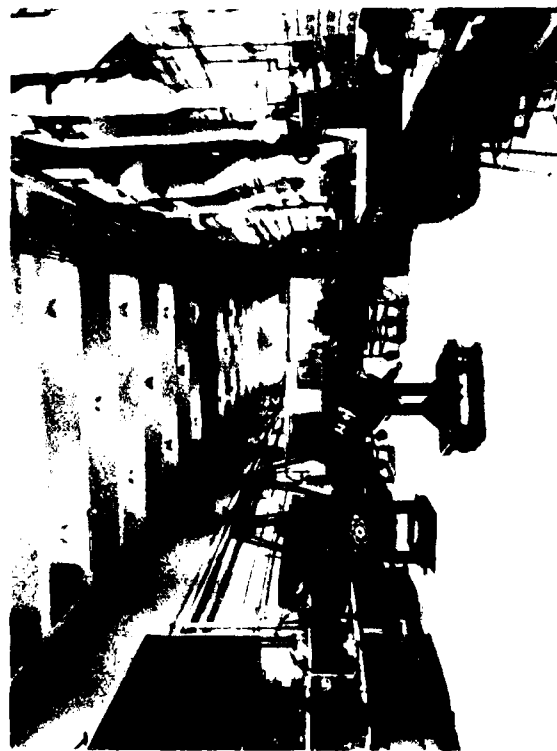
The principal steam generator components that support the Systems Depth Test Facility are shown in the accompanying photographs. At bottom is the boiler itself. At top left is the steam generator; the steam line can be seen running to the superheater, with the main steam line and safety valve at the extreme left. The top right photograph shows the electric distilling plant and 1000-gallon storage tank for production of boiler feedwater. The plant is completely self-supporting.

# Thermal Propulsion Support Laboratory





ADCAP Assembly Area



ADCAP Assembly Area

The Thermal Propulsion Support Laboratory contains the equipment required for the assembly, disassembly, pre-run checkout, and modification/repair of thermal engines and expanders. Test items made ready here are tested in the Component Test Facility or Systems Depth Test Facility and then returned to this laboratory for the turnaround process. The laboratory is equipped with a ventilation system designed to handle toxic fumes from propellants and cleaning agents. It is also fitted with appropriate personnel protection devices, holding sumps, and drains.

The northern end of the laboratory is shown in the two views to the left. Until completion of ADCAP propulsion system development, this portion of the building will be completely dedicated to turnaround of the Mk 48/ADCAP propulsion systems. Service equipment in this area includes hydraulic fluid power supplies, a hydraulic pressure service system, a cleansing bath, engine dollies, and a store of consumable spares.

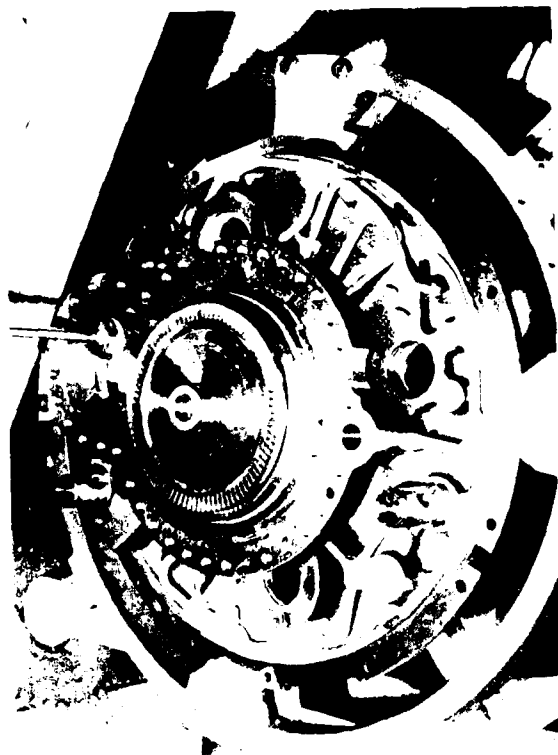
The southern portion of the laboratory is dedicated to the support of propulsion systems in the exploratory or advanced stages of development. It contains a small machine shop and equipment for the assembly, disassembly, and checkout of engines and expanders. The Wankel expander is currently undergoing service testing in this area, as is the MASTOR turbine expander. This part of the laboratory will support the development of advanced thermal propulsion systems, as well as any mechanical work in support of an independent research device.

## Thermal Propulsion Support Laboratory (Cont'd)

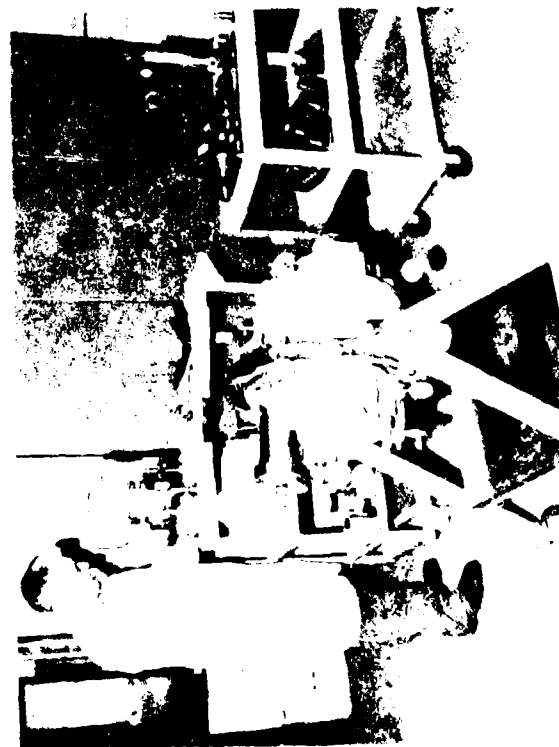
### Experimental Thermal Propulsion Engine Preparation Area

The assembly area in the southern end of the Thermal Propulsion Support Laboratory is dedicated to the servicing of experimental propulsion systems as shown in the photographs here.

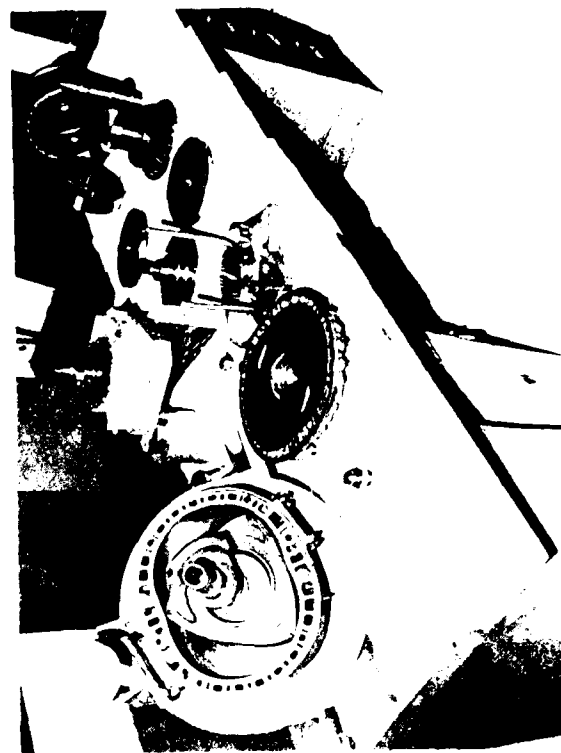
At bottom left, a MASTOR engine is shown on a handling dolly, as a technician inspects components on the engine. Top right photograph shows the turbine and accessory housing for the MASTOR engine. At bottom right, the main components of two Wankel-type expanders are shown during an inspection. Forthcoming exploratory developmental testing will be supported in this part of the laboratory.



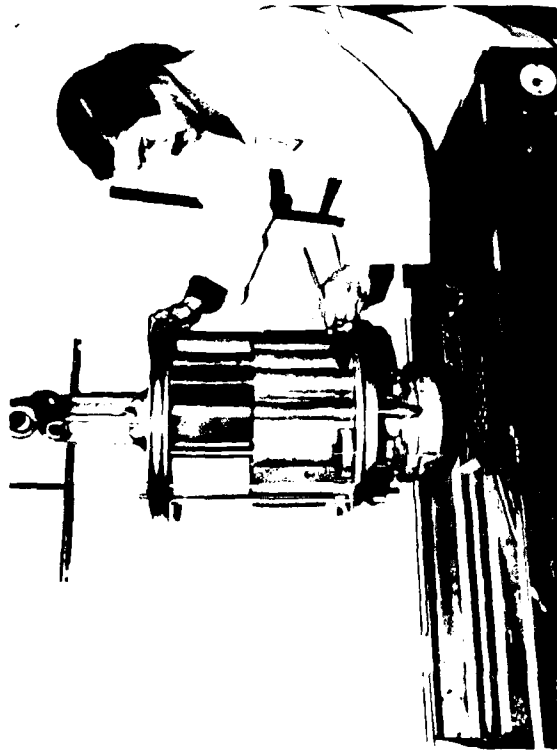
MASTOR Turbine Assembly During Buildup



Engine Buildup



Two Wankel Expanders in the Inspection Cycle (The smaller one is the RE-1-11 sized for ALWT use)



*Cylinder Block - Accessory Drive Assembly Being Removed from Cleaning Tank*

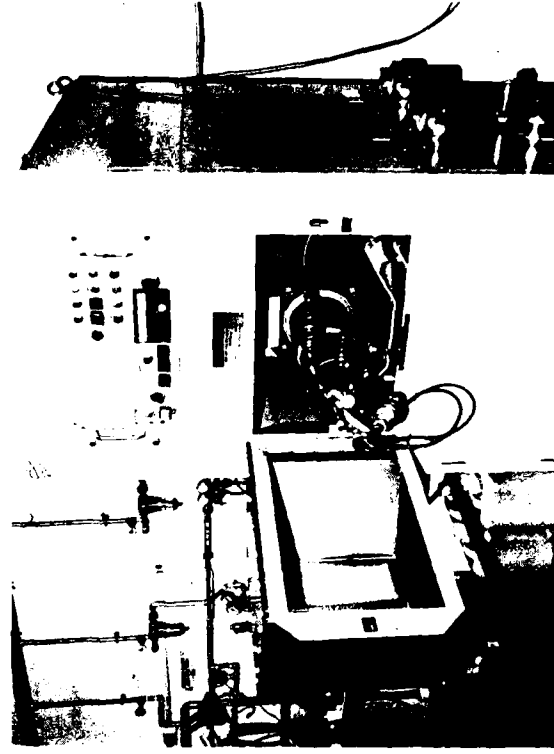
## **Mk 48/ADCAP Engine Preparation Area**

This area of the Thermal Propulsion Support Laboratory is completely equipped for the handling, component testing, and turnaround of Torpedo Mk 48 Mods 1, 3, 4 and ADCAP propulsion systems and components. For the Mk 48 propulsion system, this laboratory is as fully equipped as a Navy intermediate maintenance activity and can quickly overhaul and return development engines and components to the ready-for-test condition after test runs in the Systems Depth Test Facility or Component Test Facility.

The bottom right photograph shows laboratory test equipment specially built for checkout of the Mk 48 ADCAP fuel pump and speed control valve. At bottom left, a torpedo tail section undergoes control surface actuator checkout. In top photograph, the cylinder block for the Mk 48 ADCAP swashplate engine is cleaned as a part of the engine turnaround process.

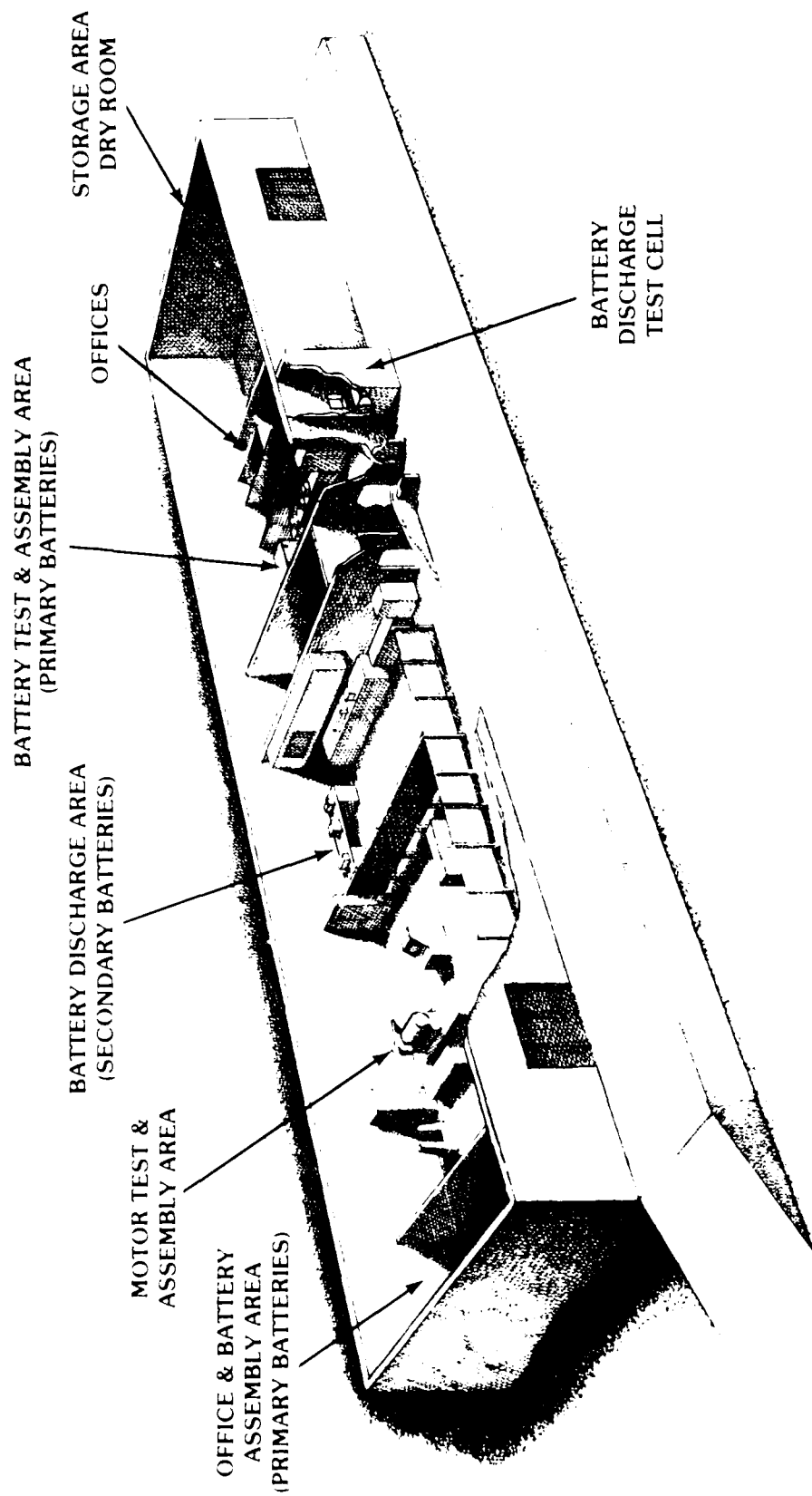


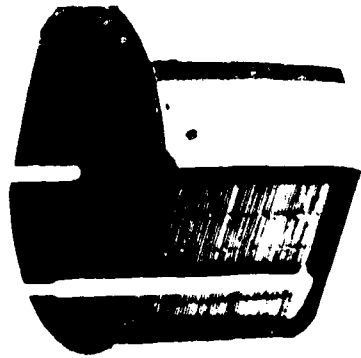
*Hydraulic Test of Torpedo Actuators*



*Mk 48 / ADCAP Fuel Pump and Speed Control Assembly Undergoing Checkout Test*

# Battery Test Facility





*Pile Battery Assembly*



*Flowing Electrolyte Test Stand*

The Battery Test Facility consists of a test and assembly area for primary batteries, and a charge and discharge area for secondary batteries. This facility has been the focal point for the initial developmental testing of the NUSCAL battery in the ALWT technology assessment and advanced development programs, as well as for testing state-of-the-art secondary batteries.

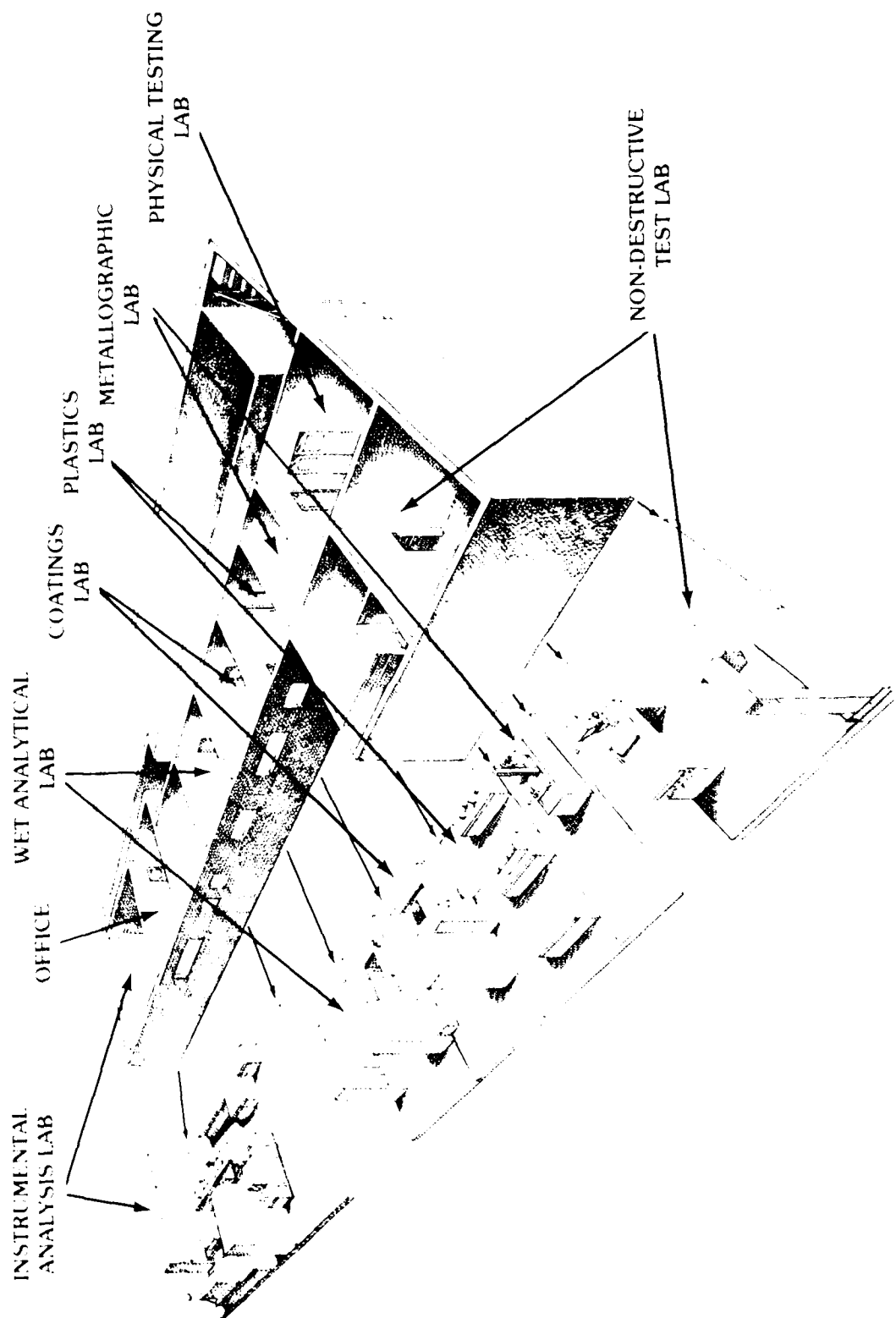
The size of the battery that can be tested in this facility is limited because of the hazardous nature of the testing. When battery size exceeds the capabilities of this facility, testing is transferred to the Component Test Facility.

The photograph at top left shows the assembly of a NUSCAL pile battery; terminals and plate edges can be seen. The battery structure is open to permit the free flow of electrolyte for gas and heat removal when in operation. The top right photograph shows a test fixture used for testing small groups of cells for the NUSCAL battery. The electrolyte (potassium hydroxide) is circulated under pressure through the cells, which are placed in the battery test fixture shown in the bottom photograph.



*Battery Test Fixture*

# Materials and Chemistry Laboratory



The Materials and Chemistry Laboratory is equipped to perform both physical testing and qualitative quantitative analysis of materials used in the fabrication and operation of underwater weapon systems. The laboratory is subdivided into areas of functional testing as shown in the isometric diagram on the opposite page.

One end of the laboratory is devoted to mechanical testing and failure analysis of metals. This area includes a Non-Destructive Test Laboratory, where X-ray and magnaflux examinations are conducted to reveal porosity and material defects; a Physical Testing Laboratory, where destructive testing is done to measure tensile strength, creep, and hardness of materials; and a Metallographic Laboratory that accommodates etching solutions and other specimen preparation items, as well as a camera-equipped microscope for examining specimen grain structure, and a macro-camera for documenting failure analysis.

Three materials laboratories occupy the central portion of the building. The Plastics Laboratory is involved with the testing and fabrication of plastics, rubbers, and composites; materials can be heated, bonded, cured, and tested for abrasion and hardness; the bonding of specimens to organic and inorganic materials can be examined; and the integrity of composites can be analyzed. The Coatings Laboratory is equipped for the testing of paints under thermal or corrosive stress; coatings can be analyzed or reduced for further analysis. The Wet Analytical Laboratory is used to perform inorganic determinations and preparatory reactions.

An Instrumental Analysis Laboratory occupies the other end of the building. This laboratory has modern equipment that can perform exact qualitative and quantitative analysis of most of the materials encountered in underwater weapon systems--whether metallic, organic, or transitional in nature. Fuels, combustion products, battery electrodes, and battery electrolytes are regularly examined here, with particular attention to composition and trace contaminants.

Some of the specialized equipment available in the Materials and Chemistry Laboratory is shown in the photographs at the left. At top is an infrared spectrophotometer for organic materials analysis. Upper center photograph shows a gas chromatograph used in the analysis of exhaust products and for battery work. Lower center photograph shows an atomic emission spectrograph. At bottom left is a powerful microscope with Polaroid camera attachment and zoom lens. Bottom right shows polarographic analyzer and stripping voltammeter used in fuel determinations.



# Summary of Propulsion Test Facility Capabilities

## Instrumentation and Control Center

Data Acquisition and Analysis Capabilities:

- Expanded PDP-11 34A computer system:  
16-bit machine with 12-bit A/D converter

Maximum sampling rate: 13,000 samples/second (128 channels)

Typical sampling rate: 100-400 samples/second (30 channels)

Storage capacity:  $14 \times 10^6$  samples

Communication with VAX-11 780 at NUASC (Bldg. 679)

On-site plotting/tabulating capability

- Five 24-channel analog recorders
- Four VCRs for readout of real-time meters
- Magnetic tape (for archives)

## Component Test Facility

- Power absorption - motoring dynamometer: 125 hp, 6000 rpm, single rotation, dual direction
- Electric load banks - water cooled: 250 kW to 600<sup>+</sup> amps  
air-cooled: 100 kW
- Electric power supply - 650 amps @ 500 volts dc
- Calorimeter system - 1000 gallons, temp control: 34°F - 100°F

## Component Test Facility (Cont'd)

- Seawater supply - 1000 gallons
- High-pressure air supply - 3000 psig, temp control to 200°F
- Local and remote control of test items and facility interfaces

## Systems Depth Test Facility

Deep Depth Test Cell:

- Pressure rating - < 2500 psig
- Pressure vessel size - 36 inches in diameter, 30 feet long
- Makeup pumping capacity - 75 gpm (salt or fresh water)
- Remote control of pressure - water supply/exhaust pressure
- Thermal conditioning - 34°F - 100°F
- Exhaust pressure auto control - bias to depth pressure with remote offset  $\pm$  100 psi
- Fuel storage tanks - 7 cubic feet, stainless, 3000 psi  
10 cubic feet, stainless, 3000 psi
- Salt and fresh water tanks - 6000 gallons
- Power absorption - water brake dynamometer:  
Single rotation: 20 - < 1000 hp  
Counterrotation: < 500 hp shaft
- Hydrostatic test capability:  
Internal pressure - up to 10,000 psig per test item  
External pressure - < 2500 psig
- Remote control of test item and facility interfaces

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## **Systems Depth Test Facility (Cont'd)**

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### Noise Test Cell:

- Power absorption - water brake dynamometer:  
Single rotation: 20- < 750 hp/shaft  
Counterrotation: < 200 hp/shaft
- Disk drag dynamometer - 200 hp, single or counterrotation
- Electric power supply - 650 amps @ 500 volts dc
- Steam supply - 6000 lb/hr, up to 2000 psig, to 1300°F
- Remote control of test items and facility interfaces

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## **Thermal Propulsion Support Laboratory**

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- Capability to handle Ottofuel and exhaust products
- Turnaround checkout of Mk 48/ADCAP systems
- Assembly checkout of exploratory turbines and Wankel expanders
- Machine shop fabrication modification capability

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## **Battery Test Facility**

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- Charging discharging capability: to 20 kW
  - Dry room for lithium handling (12 by 15 feet)
  - Silver storage area (512 cubic feet)
  - Electrode and electrolyte analysis
  - Assembly capability for single and multiple cell batteries
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## **Materials and Chemistry Laboratory**

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- Metallographic laboratory
  - Non-destructive testing laboratory
  - Physical testing laboratory
  - Plastics laboratory
  - Coatings laboratory
  - Wet analytical laboratory
  - Instrumental analysis laboratory:
- Gas chromatograph  
Infrared spectrometers  
Vapor fractometer  
dc argon plasma atomic emission spectrometer  
Polarographic analyzer/stripping voltammeter  
Electronic titration analyzer

# Propulsion Test Facility Personnel and Services

## Staffing

Personnel of the NUSC's Power and Propulsion Branch provide the technical direction and analysis of the research and development work performed within the Propulsion Test Facility. This staff is augmented by on-site contractor personnel who operate and maintain the facility under a government-owned - contractor-operated (GOCO) agreement.

The staff and test facilities are capable of providing test support to multiple customers and programs. Facility personnel possess the expertise necessary to support all portions of testing for the development cycle of both electric and thermal torpedo propulsion systems.

## Other Services and Expertise Available

Some of the expertise and more significant services provided in support of the Propulsion Test Facility are outlined below.

**Materials and Chemistry.** Materials and chemistry support for the Propulsion Test Facility involves the areas of electrochemistry, propellant chemistry, polymer chemistry, failure analysis, ecology, and corrosion. Services include original development efforts on power source components such as batteries and fuels, as well as the analytical testing of materials.

The continuing effort to increase the power densities of both electric and thermal propulsion systems has led to investigations in the areas of extraordinary thermal and mechanical stress often involving exotic materials. Laboratory personnel analyze fuels and mechanical structures during the production and fabrication of developmental items and, in addition, analyze failures, combustion products, and corrosion and erosion of test items.

**Electric Propulsion.** NUSC's propulsion personnel have developed and evaluated the electric propulsion systems of torpedoes, mines, and targets since the 1950s. These efforts have involved both the development and testing of batteries, controls, and motors, as well as the testing of auxiliary support equipment. Personnel continue to work on the development of such power sources for future weapons and manned unmanned underwater vehicles.

Personnel are also involved with the development of propulsion motors and solid-state inverters to more efficiently utilize the increased energy available from primary batteries.

**Thermal Propulsion.** Heat sources involving the combustion of high-energy monopropellants, bi-propellants, and the chemical reaction of molten metals with powerful oxidizers are all under investigation for use in torpedoes. Personnel are currently involved in improving and upgrading the Mk 48 ADCAP torpedoes. Development testing of thermal expanders, both open-cycle and closed-cycle, is also in process. Following some modification of the test facilities, personnel will test advanced thermal propulsion systems that use the heat from a chemical reaction to produce steam from the water stored in the system.

Another function of facility personnel is the testing of fuels and oxidizers both for propulsion capacity and for stability, toxicity, and handling under expected conditions of storage and service use.

**Other Areas.** Less obvious propulsion system support areas include ecological investigation and preservation of weapons in marine environments. In these areas, facility personnel are involved with corrosion studies, materials selection investigations, and the development of protective coatings and treatments.

END

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