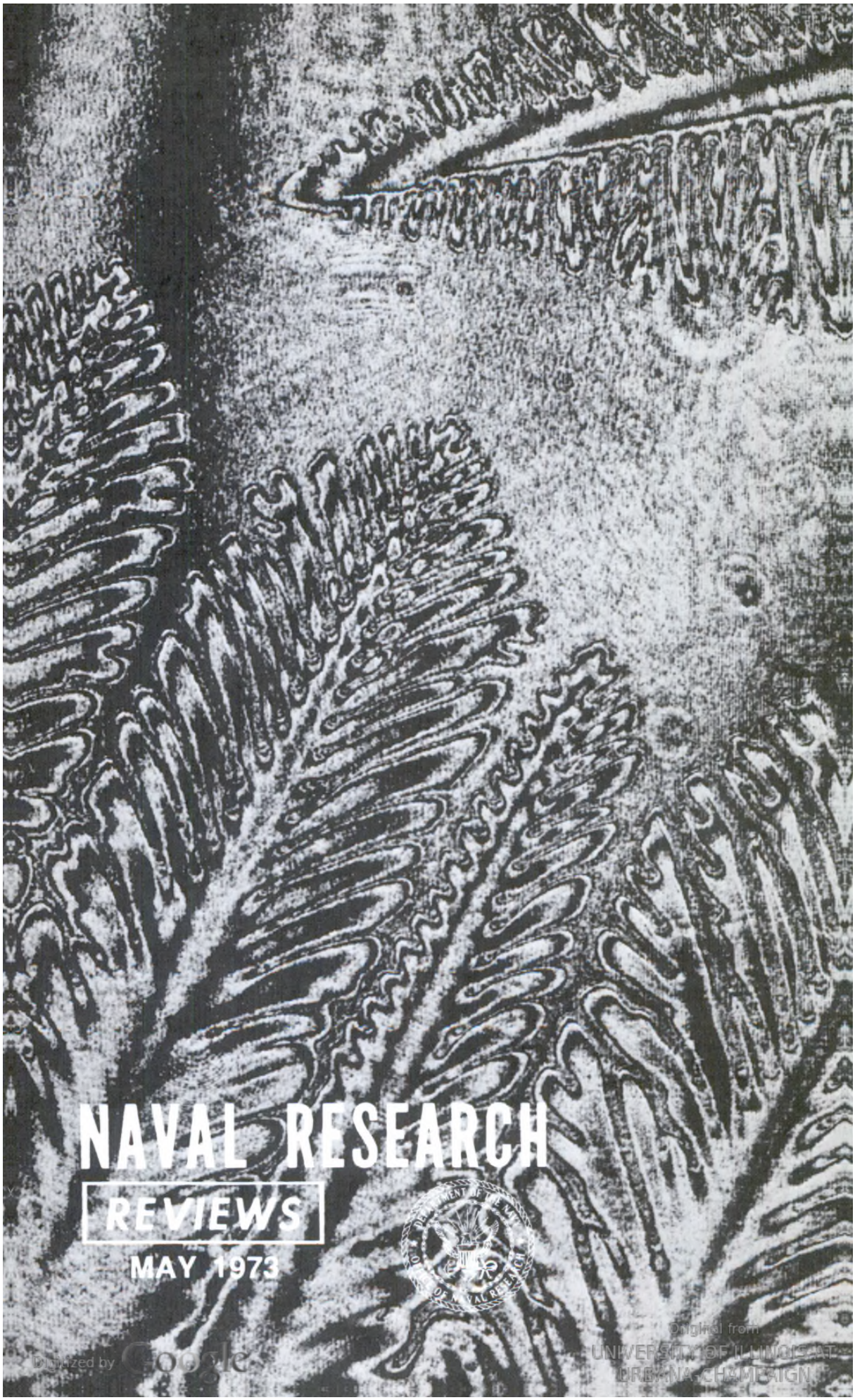

# New Chief of Naval Research

*RADM Merton Dick Van Orden*

Rear Admiral Merton Dick Van Orden, USN, has assumed the post of Chief of Naval Research, relieving Rear Admiral Carl O. Holmquist, USN, who retired as of June 1. RADM Van Orden, 52, who is a native of Austin, Texas, took command of the Office of Naval Research at a change-of-command ceremony held at the Naval Research Laboratory on May 31. He was previously Vice Commander of the Naval Electronic Systems Command.

As Chief of Naval Research, RADM Van Orden will supervise the activities of ONR Headquarters, as well as the Field Activities of ONR including the Naval Research Laboratory, Washington, D.C.; the Naval Arctic Research Laboratory, Barrow, Alaska; the Naval Biomedical Research Laboratory, Oakland, California; and ONR Branch Offices in the United States and London, England.

RADM Van Orden, a member of the U.S. Naval Academy class of 1945, has been closely associated with electronics and communications research and development throughout his career. His early assignments included studies at the Massachusetts Institute of Technology, from which he received a B.S. degree in Electronics Engineering in 1949. In 1956, he was assigned to the Naval Electronics Laboratory, San Diego, as Program Officer for Research and Development in Project Omega, the Navy's advanced world-wide navigation system.

In 1960, RADM Van Orden became Electronics Research and Development Officer and Program Control Officer at the Defense Communications Agency. After earning an MBA degree in Business Administration from George Washington University in 1964, he served for four years as Project Director of Satellite Communications in the office of the Chief of Naval Operations and at the same time Project Manager of Satellite Communications for the former Bureau of Ships and the Naval Electronic Systems Command. During this period (1968) he attended The Advanced Management Program, Harvard Graduate School of Business Administration. In 1969, he was appointed Commanding Officer, Naval Electronics Laboratory Center, San Diego. In January 1972, he reported to the Naval Electronic Systems Command.

RADM Van Orden is a qualified scuba diver and has participated in several scientific dives. He is also the author of *The Book of United States Ships*, an illustrated book for youth. He is married to the former Nancy Platt of Kingsport, Tennessee. They have two children, Anne Van Orden Coerr and Richard Platt Van Orden.

# Metallurgy at NRL—Science and Technology in Partnership*



**W. S. Pellini**†
*Naval Research Laboratory*

*This paper presents a brief historical review of developments that have influenced the present organizational structure and programs of the Metallurgy Division. Of foremost consequence was the almost total restaffing of the Division, which began in the late 1950's and extended through the 1960's, resulting in a young membership of interdisciplinary characteristics. This development has provided a high degree of flexibility in the organization of research and technological activities, which are conducted in close connection and with common aims for the resolution of critical technological problems in the metals-related field. The emphasis on cooperative interdisciplinary efforts has resulted in numerous informal and formal team activities that include the various Branches of the Metallurgy Division as well as other Divisions of the Naval Research Laboratory.*

## Introduction

The early studies of the Metallurgy Division during the 1930's and 1940's emphasized casting research, armor plate development, and metallurgical aspects of welding.

During the late 1940's and early 1950's there was a diversification of research objectives, accompanied by the introduction of new staff members versed in physics disciplines. In 1954 a major Laboratory reorganization resulted in the transfer of a substantial part of this membership to form a new Division, leaving a skeletal structure. There followed a period of restaffing, largely with new graduates, which brought the Division back to nearly full strength by the early 1960's.

The restaffing provided the opportunity to evolve an entirely new program structure in which the emphasis was placed on physical metallurgy, mechanics, and metal physics. Selective additions of mechanical engineers, chemists, physicists, and materials scientists have continued to enhance this structure to the present time. The objective has been to develop a highly flexible scientific staff that could be focused on primary technological issues in the metals-related field with a minimum of organizational difficulty. From 1960 to this date the Division program

*Dr. Pellini is Superintendant of the Metallurgy Division at the Naval Research Laboratory. His main field of interest is mechanical metallurgy and fracture safe design.

†Reprinted from *Report of NRL Progress*, February 1973.

structure has been modified substantially in 5-year cycles to include the most modern areas of research.

The main strengths of the Division lie in five general areas that correspond to the charter research objectives of the five Branches. These include:

Strength of Materials and Fracture Mechanics
Environmental Mechanics and Corrosion
Nuclear Reactor Materials
Physical Metallurgy and Materials Sciences
Basic and Applied Metal Physics

The organizational and disciplinary structures of each Branch have been designed to contribute equally to scientific and technological issues. Each of the groups has achieved an international scientific reputation, while participating in selected areas of application that include solutions of engineering problems. The following review of program area activities is presented in relation to the charter assignments of the individual branches.

### Strength of Materials and Fracture Mechanics

Classical procedures for the characterization of strength properties are based on the use of conventional tensile tests. The property that is measured may be defined as the "smooth body" strength, *i.e.*, the ideal load bearing capability when no cracks are present. During the past decade, analytical procedures that include crack effects have been developed for measurement of fracture strength properties and for structural design. These procedures are known as fracture mechanics.

The principles of fracture mechanics may be applied to problems involving the initiation and extension of catastrophic fracture, slow crack growth due to fatigue and stress corrosion cracking (SCC), and generally to the characterization of materials properties in relation to these engineering factors. NRL has played a major role in developing they theory, analytical methods, and standardizing tests, and in translating all of these aspects to engineering practice. The naval importance of these developments lies in the fact that effective use of modern high-strength materials depends on the understanding and proper application of fracture mechanics principles.

The scientific studies have included the microscopic aspects of fracture processes and the rationale for connecting microscopic events to the measured mechanical properties. The results have provided entirely new principles for control of fracture properties by rational methods of alloying and heat treatment. Accordingly, metal improvement objectives have become more definable and attainable with much smaller

expenditures of time, effort, and money than were required by previous empirical methods.

The practical value of the new principles depends on the development and use of new types of highly discriminating fracture tests. These tests must be used for specifications and quality control purposes and require standardization through a process of use and acceptance by the engineering community. All of the three modern fracture tests, which are rapidly replacing the older, inadequate tests, have been evolved directly from NRL research. These developments include the Drop Weight-NDT and the $K_{Ic}$ tests, which have been standardized by the American Society for Testing Materials (ASTM) and Military Specifications procedures; and the Dynamic Tear (DT) test, which is approaching standardization status.

Another NRL contribution to structural mechanics is the Ratio Analysis Diagram (RAD). The RAD provides integrated analytical procedures for translating laboratory fracture test data to useful design information. It also simplifies the selection of the most desirable metal for specific design uses and identifies directions for metal improvements.

Our present research is directed to improving procedures for incorporating stress corrosion cracking (SCC) properties and fatigue data in the basic RAD format. With these additions, the multiple RAD system will provide for sequential analyses of all primary factors related to structural reliability, as required for fracture-safe design.

These investigation have included steels, aluminum, and titanium alloys, ranging from low to very high strength levels. The principles are applicable to product forms involving sheet, thick-section plate, forgings, castings, and welds. The integration of materials, form, strength level, and mechanics factors is unique and has been documented in NRL summary reports that are being used as sole source references by practicing engineers. The reports are also used as texts by approximately 35 universities.

These NRL studies have provided the primary guidance for the development of improved metals and design criteria for a wide range of military structures. They are also of major importance to the civilian economy, since the design criteria are generally applicable to all types of engineering structures.

Our current fracture research efforts are focused on the specific needs of future submarines, aircraft, and fast surface craft. In general these needs involve increasing the usable strength levels of advanced metals with retention of assured reliability for fracture prevention. Examples include the HY-130 and HY-180 steels (yield strength level expressed in ksi) fo submarines; high-strength titanium alloys (110 to 150 ksi yield strength) for aircraft; and a broad mix of steels, aluminum, and titanium alloys for hull structures of fast surface-craft. Weldability and

weld metal properties are also investigated for these various metal systems.

The need for analytical definition of fatigue-controlled life is particularly important for high-performance structures. During the past 4 years, power law criteria for crack growth rates have been developed and introduced into general use. These criteria provide a first-order definition of the range of metal characterisitics. This preliminary phase has now been completed, and the emphasis is placed on the effects of complex loading cycles. For example, specific loading programs modeling those actually experienced by submarines and aircraft are applied to test specimens by the fatigue machine. The test results are validated by life predictions for large-scale fatigue models in cooperation with other laboratories.

### Environmental Mechanics and Catastrophic Corrosion

During the past 5 years, considerable progress has been made in scientific procedures for characterization of stress corrosion cracking (SCC) and for defining sensitivity to highly localized corrosion. Significant understanding of metal, mechanical, and electrochemical relationships has been achieved, particularly for critical regions such as crack tips and crevices. However, much remains to be learned about the dependence of environmental effects on alloy composition and microstructure. Thus, much of our research is directed to real, complex alloys in keeping with our purpose of developing scientifically sound procedures for optimization of engineering materials.

The characterization of SCC properties by fracture mechanics procedures at NRL has important long-range consequences. The original exploratory studies were conducted in the late 1950's as a consequence of SCC hydrotest-failures of Polaris rocket cases. By 1964 the work had progressed to the point of providing analytical capabilities for calculating the crack size that would result in fracture extension by SCC for specified levels of stress. Thus, the rating of corrosion susceptibility under stress was becoming an exact design tool. In 1965, we entered into a formal cooperative program, under ARPA sponsorship, with five universities and an aerospace firm. This 5-year program, with combined scientific and technological objectives, was unique in its combination of micromechanical, electrochemical, and macromechanical studies. It was a productive demonstration of the effectiveness of interdisciplinary studies for complex environmental mechanics problems and we proposed to continue this approach in a broad variety of new studies.

Microscale separation processes at crack tips, for a specified section size, determine the fracture mode, *i.e.,* brittle, semiductile, or ductile

fracture. The fracture mode determines whether the metal of a given thickness is susceptible to fracture extension or not. Thus, the micro-scale processes control structural performance, and it is critically important that we understand the factors involved. In particular, environmental effects can have phenomenal consequences—such as changing the fracture mode from ductile to brittle. These dramatic effects can result only from major changes in processes of incubation and coalescence of microcracks, between and within metal grains. These micro-process studies represent the most advanced and complex area of mechanical metallurgy, which is called crystal mechanics.

Recent studies have centered on processes of SCC and other forms of subcritical (time dependent) crack growth, involving cadmium and hydrogen embrittlement of high-strength titanium alloys. Other investigations are concerned with the phenomenon of hydrogen-assisted cracking of high-strength steels. This phenomenon is involved in SCC due to hydrogen release at the crack tip, and more generally in cases where hydrogen is present in the metal itself.

There is a crucial need for a means of defining environmental sensitivity in single-parameter terms, similar to the $K_{Ic}/\sigma_{YS}$ ratio (fracture parameter divided by the tensile yield strength) used for conventional fracture. The degradation of mechanical properties can occur on time scales varying from seconds to hours, depending on "sensitivity." As a result, design criteria cannot be developed easily because engineering characterization becomes a research problem in each case. Thus, straightforward engineering use of the principles is complicated for most practical purposes. New approaches are badly needed for characterizing the sensitivity to time-dependent cracking. We are actively investigating a number of possibilities, including one using relatively simple specimens in which the crack-tip stress intensity (K) is gradually decreased as the crack is extended.

Modern military systems involving high-strength metals and combinations of dissimilar metals face serious problems of catastrophic corrosion. This type of corrosion tends to be localized and therefore can cause destructive damage in a short time. Typical examples occur in torpedoes stored in flooded spaces, under O-ring seal of electronic devices, and in stainless steel piping containing water-base foam-forming agents for fire fighting use on aircraft carriers.

Another corrosion problem arises from intense attack due to electrical fields created around ships by shipyard power distribution networks or by electrical equipment operating on adjacent ships. The problem involves not only the effect of direct current fields, but also the synergistic effects that result from superposing an alternating current field on an existing dc field. The latter is of particular interest because of the widespread occurrence of ac fields that interact with the dc field that

exists around any multimetal structure immersed in seawater. The research objectives in this area are to identify the controlling electrochemical parameters at the metal-seawater interface and to develop scaling laws by which the behavior of engineering structures can be predicted from laboratory data. Subjects of particular interest include the division of electrical current between a metal and an electrolytic solution in which is is immersed; the specific reactions that occur at the metal-seawater interface; and the effects of sequential effects (such as hydrogen evolution) on subcritical crack growth in corrosion fatigue and SCC.

NRL studies have shown that the occluded corrodent in localized corrosion may differ greatly from the bulk environment. For example, seawater that enters a crack tip and becomes stagnant, changes to a highly acid solution due to confined reactions with the metal. We have developed micro-sampling and micro-analytical procedures to follow such changes in solution chemistry within narrow crevices and cracks. With emphasis on the effects of alloying and environmental factors, we are pursuing a research program aimed at obtaining fundamental information about the electrochemical and chemical conditions within occluded local cells, constructing rational theory, and developing countermeasures against localized corrosion.

## Reactor Materials

A decade of achievements in Pressurized Water Reactor (PWR) technology is well summarized by the following citation accompanying the American Nuclear Society special award in 1972 to an NRL scientist:

> "For outstanding contributions in developing an understanding of the embrittlement of steel by neutron irradiation, development of improved materials for service in a neutron field, and developing design and fabrication criteria and standards which today assure safety of nuclear reactor pressure vessels and steel structural components."

The primary structural reliability questions of commerciall PWR systems had been resolved by a combination of studies which included:

- establishing new principles for characterization of metal properties significant to design, *i.e.*, fracture mechanics as applicable to thick metal sections
- evolving structural mechanics analytical procedures, *i.e.*, developing scaling law relationships between laboratory tests and structural performance
- conducting reactor experiments to define property changes in (sensitivity to) reactor environments

- developing improved (radiation insensitive) metals by using principles deduced from the combined studies
- rationalizing damage and damage mitigation factors in terms of microscopic phenomena (crystal mechanics).

The overall approach is now being applied to other advanced nuclear energy systems in which metal problems are even more critical because they decide feasibility. The crucial questions include:

- temperature limits
- fracture mechanics criteria for high-temperature design, and
- extreme degradation of mechanical properties due to the environment.

Specific questions of major importance are deduced by systems analyses. Each question is considered in terms of adequacy of fracture mechanics criteria and structural mechanics analytical procedures. Appropriate experiments are then designed for studies in a test reactor or in simulated environmental conditions. Simulation is essential because of serious space and time limitations in test reactor facilities that provide appropriate environments.

Major advances in the application of fracture mechanics principles to high-temperature design problems are prerequisite to all other studies. Thus, a major part of our near-term effort is being directed to this aspect. The problems involve fracture properties that may range from low to intermediate levels of ductility. Fracture can develop under conditions that are described as "easy tearing." contrasted to brittleness for the case of ordinary temperatures. The brittle state is analyzable in terms of linear-elastic fracture mechanics, which implies the use of relatively simple elastic analyses of the crack-tip conditions. The semiductile, high-temperature state requires complex nonlinear (elasto-plastic) fracture mechanics analyses; hence the crack-tip conditions are more difficult to resolve mathematically.

The applicability of fracture mechanics procedures for quantitative analysis of fatigue crack growth due to neutron environment has been proved by recent NRL studies. In these studies the limited test reactor spaces dictate the use of relatively small test specimens. Such small specimens have a relatively low mechanical constraint, and the results must be interpreted over a wide range of constraint states (section sizes). The constraint-equivalence factor is the most challenging aspect of the advanced fracture-mechanics criteria problem. We are placing considerable emphasis on these studies, because the criteria definition problem is crucial to all other strength-related questions.

Prior studies of radiation damage mechanisms have been concerned with micro- and macro-plasticity factors. We are also investigating the

role of lattice-level defect structures, evolving from neutron displacement of lattice atoms, and their interactions with interstitial elements and/or with moving dislocations. The defect structures are studies primarily by means of transmission electron microscopy and the results should aid in understanding specific embrittlement sensitivities and in rationalization of damage functions.

Another important aspect of these investigations involves the conditions for genesis and growth of microscopic voids that cause critical swelling problems in fast reactor, fuel-element cladding. The void growth problem is partly involved with questions of the role of helium created by transmutation reactions.

The studies of void growth mechanisms have fostered a cooperative radiation effects simulation program (CORES) with the Nuclear Sciences Division, to capitalize on the use of charged particle simulation. Neutron radiation damage accumulating in reactor metals in years can be simulated in hours by selected charged particle irradiations. The NRL 5 MeV Van de Graaff and sector-focusing Cyclotron have been modified to provide the needed irradiations by the development of special beam facilities. Through a series of bombardment cycles, the principal neutron damaging phenomena are duplicated under carefully controlled conditions. Heavy ions (Ni, Nb, *etc.*), alpha particles (He), and protons will be used for parametric evaluation of radiation damage of metals and for systematic explanation of the fundamental processes involved. Complementary computer modeling and in-reactor experiments are used to confirm charged particle irradiation effects.

### Physical Metallurgy and Materials Sciences

NRL work in basic processes of solidification has been focused uniquely on neglected ultra-microscopic aspects and has earned widespread scientific recognition. During the past two years the research program has expanded considerably, with the objective of understanding and controlling microscale phenomena.

In the utilization of new materials or exotic combinations of materials, deviations from the ideal material state become functionally limiting. These deviations often occur when carefully controlled research materials are "scaled-up" to complex structural forms. These problems are particularly crucial in the area of sophisticated electronic applications, because performance frequently is totally limited by available materials technology.

The problem of bridging this gap is twofold:

- first, the phenomena linking the structure of a material to its properties and responses must be understood—including the roles of defects and impurities;

- second, a methodology for controlling the properties by practical structural modification must be developed independently through study of the effects of fine-scale processing on microstructure.

The solid-state portion of the transformation work utilizes novel pulse-heating equipment to study fast transformations of the massive-martensitic and order-disorder types. Reactions occurring on a millisecond time scale are observed kinetically. Liquid-solid transformation studies are focused primarily on the questions of morphological development and perfection of melt-grown crystals. The novel application of powerful holographic techniques, with the support of the Optical Sciences Division, has made possible observation of morphological development in great detail during the freezing process. This relatively recent application of holography has already yielded significant improvements in our understanding of the complexities of crystal growth. Present studies of solidification and melting are concentrated on advanced theoretical treatments of dendritic growth and rapid melting induced by high-intensity heat fluxes.

We intend to continue basic studies of fast transformations with the goal of uncovering and understanding the subtle but very important changes that such unique conditions produce in metals. Fast or transient transformations may evolve due to thermal excursions induced by an electromagnetic pulse, laser flash, electrical discharge, *etc*. In addition, mathematical studies of microscopic and macroscopic heat flow in transforming (melting and freezing) metals will be continued. These studies are providing essential theoretical methods needed to solve laser-induced melting problems and are shedding important new light on the long-standing problem of dendritic growth in cast metals. Projected work in this area will involve fundamental analytical studies of dendritic side-branching which is responsible for micro-segregation in alloys—one of the major technological problems associated with all cast materials.

We are also studying the critical roles played by defects in the transformation and processing of metals. The program includes studies of lattice vacancies and interstitials (point defects), dislocations (line defects) and grain boundaries, and interphase interfaces (surface defects). The formation and motional engeries of lattice vacancies (both thermally and radiatively induced) are studied with high-precision dilatometry and small-angle x-ray scattering. Vacancy motion and agglomeration are analyzed through use of micro-elastic continuum models, which describe events on the near-atomic scale. A subsidiary program is devoted to measuring the single-crystal elastic constants of metals up to the melting point and contributes critical input data for assessing dislocation energies and stability.

Present studies of electronic materials are concerned with the effects of metallic structure on the electronic properties of materials for microcircuit and superconducting applications. This work focuses on the relationships between the metallurgical factors that affect structure-sensitive electronic properties. Advanced experimental methods such as He-ion backscattering and laser-generated shock wave analysis are used to measure the extent of reaction, interdiffusion, and bonding between microcircuit metallizations and the underlying semiconductor or insulating substrate.

We plan to expand our work on electronic microcircuit materials, particularly in the area of diffusional transport at metallization-substrate interfaces, with improved circuit reliability as the technological goal. However, the program must also address numerous basic metallurgical questions about the effects of deposition parameters on film and interface structures: their influence on matter transport during circuit operation (*i.e.*, materials compatibility), and diffusion processes in electrically active films and overgrowths; and the very critical problem of making meaningful measurements of the adherence of metallizations to ceramic and semiconductor substrates.

The control of structure and properties is effected through a wide variety of chemical, thermomechanical, and heat-treatment processes which determine, directly or indirectly, the amount and distribution of phases and defects in a material. These studies are concentrated on developing processing procedures to improve the properties and performance of superconductors for used in advanced Navy cryogenic propulsion, communication, and detection systems. Specifically, solidification, solid-state diffusion, and transformation processes are used to modify microstructural elements in metallic materials to enhance their performance and stability and to extend their reliability and usefulness. Currently, both ductile (alloy) and frangible (compound) superconductors are under study to provide the widest range of choices of superconducting systems.

The results of the processing and electronic materials programs will be applied to fabricate superconducting communications components for use at shipboard power levels (kilowatts at 10 to 30 MHz). Currently, we are cooperating with NRL's Communications Sciences and Solid State Divisions in making an all-niobium, high-Q, resonant tank circuit which demands scrupulous attention to the fabrication (*via* electron beam welding) and surface preparation of the niobium (electropolishing and anodization). The fabrication effort is also supported by research on the influence of substrate and fine-particle dispersions on the superconducting properties of niobium-carbon alloys. This study should provide detailed information on optimal microstructures for specific electronic applications of this important type-II superconductor.

## Basic and Applied Metal Physics

The total program is divided into three overlapping research activities: (a) studies of the electric and magnetic properties of metals, alloys, and intermetallic compounds; (b) the interaction of laser radiation with materials; and (c) the thermomechanical response of metallic systems to intense pulsed irradiation.

Basic studies of magnetic and electronic phenomena are of fundamental importance to the development of materials with special properties. These materials are generally alloys whose unique properties depend on subtle physical phenomena. The understanding of these controlling phenomena is essential and requires fundamental investigations of the detailed electronic structure of pure metals and alloys.

The simplifying feature of pure metals which makes their properties understandable in terms of tractable theoretical models is their essentially perfect crystal-periodicity. Alloys do not have this simplifying feature and, in fact, derive many of their properties from their aperiodicity. Thus, in keeping with our thrust toward the development of new, technologically useful materials, much of our effort in this area is centered on alloy systems, particularly those with either special crystallographic properties of highly sensitive responses to small perturbations of their electronic structure.

Among the phenomena most sensitive to alloying are the magnetic effects. Nonmagnetic palladium, for example, becomes ferromagnetic when as little as a few hundred parts per million of iron are added. By studying such effects of small amounts of magnetic impurities in pure metals and their selected alloys, we can isolate those properties responsible for their unique magnetic behavior and develop our knowledge of magnetic materials in general.

Our experimental work on electronic structure utilizes a de Hass-van Alphen apparatus incorporated into a $10^5$ gauss superconducting solenoid magnet, and an angular correlation, positron annihilation apparatus which we have developed and built. The positron-annihilation equipment features a unique gamma ray collimator that provides substantial increased in angular resolution. Both techniques are used to map the electronic structures of compounds, imperfect single crystals unobtainable in the perfect state, and concentrated alloys. We are also investigating electric and magnetic properties such as low-temperature specific heat, electrical and thermal conductivity, magnetization, and magnetic resonance to complement the electronic structure mapping and to enhance our understanding of ferromagnetism and magnetization.

Our plans include extension of the positron annihilation investigations of single crystals; modification of the specific-heat equipment to permit measurements in magnetic fields at temperatures down to 4.2K;

growth of high-quality single crystals of intermetallic compounds; low-temperature specific heat measurements of Pt-Ni alloys; resistivity and magnetization studies of PtNiFe and PtNiCo ternary alloys; and exploratory studies of layered superconductors.

We are also engaged in magnetostrictive studies to provide a scientific basis for understanding, predicting, and manipulating the subject properties of metals, alloys, and intermetallic compounds, especially those which may find application as transducer materials. The effects of changing temperature, alloy composition, and thermal treatments are measured and then analyzed in terms of microscopic theories, to produce materials of optimum characteristics.

These magnetostrictive studies have included $Tb_xHo_{1-x}Fe_2$ ternary compounds, near the composition $x = 0.15$, which exhibit relatively low anisotropy with high magnetostriction. We have shown that annealing these compounds generally increases their magnetostriction. Future plans include investigations of $Gd_xR_{1-x}Fe_2$ and $RNi_2$ compounds (where R is a rare earth metal), effects of temperature on magnetocrystalline anisotropy in selected $RFe_2$ compounds, and comparisons of rare earth compounds prepared by melting and nonmelting techniques.

The new studies of laser effects have been largely concerned with purely thermal effects and recently have been extended to include pulse-thermal conditions involving lasers of intermediate to very high energy characteristics. The research is concerned with the interaction of coherent (cw and pulse) laser energy with metals. The details of the energy-coupling process are important to a variety of laser applications such as welding and fabrication, as well as for other military uses.

In the initial stages of the energy-coupling process, high-temperature optical and thermal properties of the solid are involved. When melting begins, liquid state properties also become important. Hence the high-temperature properties of relevant structural materials in the solid and liquid states are being examined. The optical properties are being studies at wavelengths from the ultraviolet to the far infrared. Raman studies are probing the nature of the coupling of the optical energy to the metallic system. Mechanical aspects are included by examination of the laser-heated zones in both metals and composite materials. The objectives are to understand the nature of the heat flow processes in both isotropic and nonisotropic materials and to develop procedures for minimizing the detrimental mechanical effects of the thermal excursions.

The abrupt deposition of large amounts of radiation energy in a material can also produce elastic or plastic shock-waves as a result of surface vaporization and transfer of the ejecta-impulse to the material. Such shock waves can cause mechanical damage in the form of

spalling and/or severe fissuring and cracking, to a degree that depends on the energy deposition rate and the microstructural nature of the material. Other effects may also occur, such as preferential heating of specific microstructural phases, depending on the source of energy. The thermal excursion effects may be particularly severe in materials such as metal-matrix composites where the sudden preferential heating can rupture the bond between the metal matrix and the strenthening, nonmetallic filaments.

New studies in these areas are concerned with exact characterization of the incident energy by suitable dosimetry, measurement of mechanical and/or thermal signatures, and definition of the resulting mechanical damage. This information is analyzed with respect to the microstructural factors, from which hardening concepts are evolved. The ultimate objective is to evolve improved materials with higher intrinsic resistance to damage by specific types of radiation.

### Summary

This "Overview" of the Metallurgy Division has provided a broad description of a highly flexible, interdisciplinary group, engaged in a spectrum of challenging scientific and technological activities. An important aspect of these operations is the considerable emphasis that is placed on structuring team efforts involving elements of the various Branches and cooperative interactions with other Divisions. The intent is to bring all avaliable resources to bear in attacking problem areas of foremost scientific and technological importance to the Navy and the Department of Defense. These combined efforts amplify the contributions of specialized disciplines and, therefore, are highly productive.

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## Mechanical Properties of Metals and Polymers

A Workshop on the Strength Differential in Metals and Polymers was held at the Office of Naval Research Office in Boston. Organizers were Professor Morris Cohen, M.I.T.; Dr. Bruce A. MacDonald, ONR Washington; and Dr. Frank S. Gardner and Dr. Leighton H. Peebles, Jr., ONR Boston. Approximately 50 attendees with university, industry and government affiliations participated in the two-day session.

*(Continued on Page 28)*

# The Evolution of Marine Organic Chemistry

**M. Blumer***
*Woods Hole Oceanographic Institution*

*The Office of Naval Research is sponsoring Dr. Blumer's research to gain a clearer understanding of organic matter in the marine environment. The variety of the organic compounds in the sea far exceeds that of all inorganic species combined; yet, very little use has been made of organic analysis in solving problems about the oceans. One of the reasons for the lack of knowledge in the area of Chemical Oceanography has been the general unavailability, until recently, of sufficiently sophisticated separation, identification, and measurement techniques to allow for such research to be undertaken. However, the field is now at the stage of development at which the instrumental capabilities and techniques required to permit intensive research in this problem area are becoming available. Dr. Blumer is taking advantage of these developments, as well as utilizing his own, in undertaking a research program on organic compounds directed at providing insight into the sources, concentrations, variability, the causes of variability, long-term fate, and the interaction with other components of the marine environment. This research will provide valuable information to the Navy on corrosion processes in both aerobic and anaerobic environments, on factors enhancing or inhibiting biological fouling, on the effects of organic matter on biological populations, and on potential for pollution.*

The last decades have seen a vast expansion of basic knowledge in chemistry, physics, and biology. There has been an equally rapid growth in the basic tools of physical science; it rests largely on the phenomenal developments in solid state electronics and on the new transducers and data processing systems derived from it.

Analytical chemistry as it was taught not long ago has almost disappeared, and its place has been taken by a new art that borrows heavily from physics and mathematics. It is easy to forget how rapid this change has been. When I attended college, my university was involved with some of the early research in infrared spectroscopy. We had a "walk-in" spectrophotometer, a large room with black walls and a detector moving

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along a curved railroad track. The performance of electrical instruments was so unpredictable that one of my professors prohibited the use of chart recorders; all curves had to be plotted from readings taken off the projection scales of mirror galvanometers. Today we buy small inexpensive instruments that are superior and relieve us of much of the tedium of data acquisition and handling.

In the early days of geochemistry, scientists like Goldschmidt and the Noddacks had to develop their own analytical tools. Now, tools and knowledge are available to us that have great promise for oceanography and geochemistry. In their application lies one of the great opportunities for rapid advancement in our interdisciplinary sciences. I wish to illustrate this for the field with which I am most familiar, marine organic chemistry.

## Organic Analysis by Mass Chromatography

The organic chemistry of sea water and of marine sediments is much more complex than most chemists realize. Numerous compounds are contributed from many different sources. Organisms, recycled interstitial water from sediments, fallout from the atmosphere and man's domestic and industrial activity, all add a wide spectrum or organic compounds to the sea. In addition, biochemical or purely chemical reactions affect many compounds and lead to even greater complexity of the products.

In this complexity of marine organic chemistry, frustrating as it appears to the analytical chemist, lies its scientific challenge. A complete analysis of any sea water sample would tell us the relative importance of its sources, the extent of biological and chemical turnover, and the nature of the processes that occur in the water column. Such a complete analysis of that enormously complex mixture is still beyond reach; yet, we are closer to a meaningful partial analysis than even a few years ago. Foremost among the newer tools of the organic chemist is the combination of gas chromatography with mass spectrometry and electronic data processing.

The marriage of these three techniques is uniquely successful because of their complementary nature. Gas chromatography is primarily a very efficient separating tool. Mass spectrometry as a chemical identification technique is best applied to well-separated compounds, and the volume of data which it produces is so great that full utilization requires a high-speed data processing system.

A few comments on mass spectrometry may contribute to an appreciation of its potential in oceanography. Basically, a mass spectrometer subjects the vapor of a compound to the impact of electrons from a glowing filament (Figure 1). Ions, electrically charged molecules and

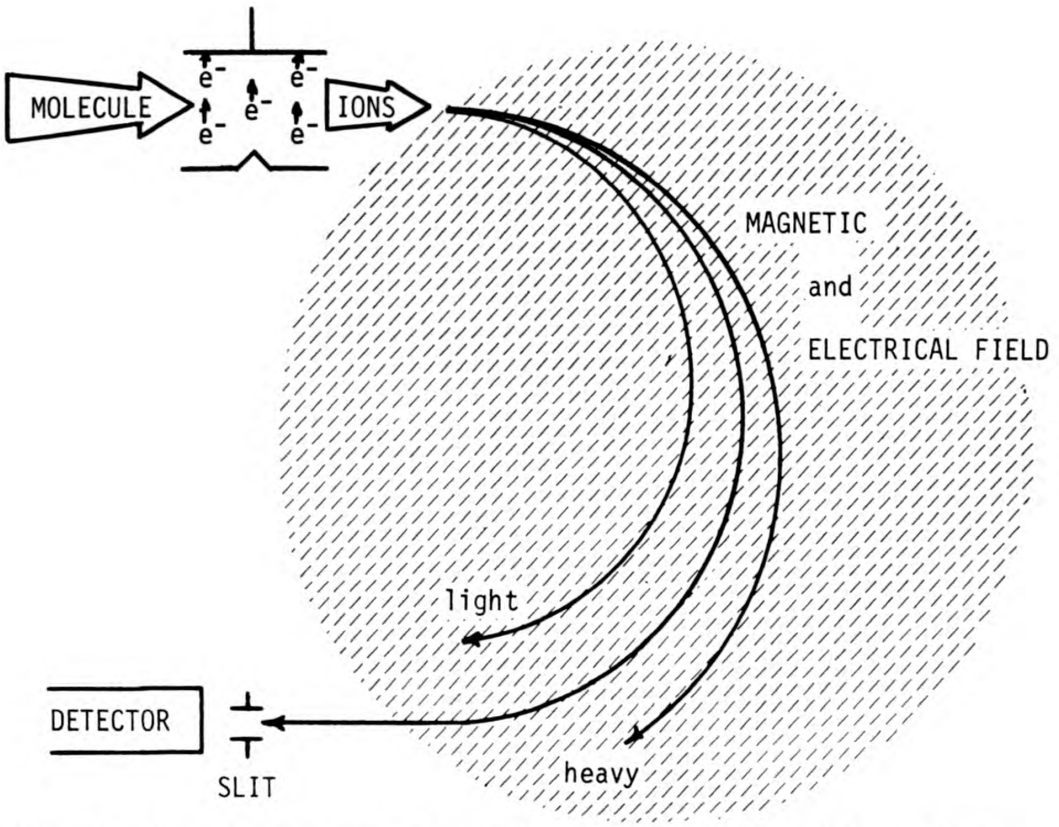


*Figure 1 — Mass Spectrometry: Gas molecules are ionized and fragmented by an electron beam. The positively charged ions are separated in magnetic and electrical fields. Ions of any desired mass-to-charge ratio are selected by a slit, and their impact on a detector produces a measurable signal (After W. W. Youngblood).*

molecular fragments, are produced, and they are accelerated and separated in a combination of electrical and magnetic fields. Their arrival on a target, after selection of a limited mass range by a slit, produces an electrical signal that is proportional to the number of ions. The mass spectrogram of an organic compound is simply a graphical presentation of the relative abundance of the ionic fragments of different masses. Its interpretation is an attempt to reconstruct on paper the original molecule from its fragment masses, in consideration of their abundances.

Initially, computers were used in mass spectrometry principally for assessing the fragment masses and their abundances, then for searching spectral libraries and for attempting computer-aided logical reconstruction of the structures of the parent molecule. In this classical sense, the art of mass spectrometry is used at its best by the oil industry in analyses of pure compounds and of complex mixtures. Aczel and Lumpkin (1972) describe the simultaneous determination in gas oils of 2000 homologous compounds belonging to up to 100 compound types. The potential of such a complete analysis of a natural product for environmental chemistry can be readily appreciated; yet, no similar comprehensive analyses have ever been made in the marine sciences.

Recently, the analysis of complex organic mixtures has advanced rapidly through the combination of gas chromatographic separation with mass spectral analysis. This has led to a new type of data treatment, *Mass Chromatography*. The composition of geochemical or oceanographic samples is so complex that even efficient gas chromatography is unable to separate them into pure individual compounds. The interpretation of the resulting mixed mass spectra, often containing fragments of unanticipated structural type, has been difficult.

In mass chromatography, mass spectra of the vapor eluting from a chromatographic column are scanned repetitively for the entire duration of the separation (20-60 minutes). The spectra are stored in digital form in the memory of the computer. Several hundred spectra, each containing a few hundred different mass fragments, may be accumulated during a single run. Later all spectra are searched for the presence of such fragment ions that may reflect specific structural features in components of the mixture. Thus, specific fragments reveal the presence of esters, ketones, straight and branched chain compounds, aromatic rings, halogen derivatives, and many others.

For example, fragments of a mass-to-charge ratio 99 (m/e = 99, $C_7H_{15}^+$) are common and relatively intense in the mass spectra of all normal alkanes. Ions of that m/e may not occur in the spectra of other compounds, *e.g.*, in aromatic hydrocarbons, or they may be present at lower relative intensity. A plot of the abundance of this fragment against the chromatographic elution time, or synonymously, against the spectral index number, shows the sequential appearance and disappearance of the individual normal alkanes in the eluant gas streams from the column (Figure 2A). The position of these peaks in the chromatogram relates to the boiling point and describes the size of the molecule; confirmation of the identification is obtained through retrieval from the memory and inspection of the most intense mass spectra recorded by the elution maximum of each component.

The use of the data from one chromatogram is not exhausted by a single search of the computer memory; many consecutive searches are possible, each for compounds of specific structural types. In that manner a complex and only partly resolved chromatogram can serve the identification of a multitude of components.

A particularly good illustration of the potential of mass chromatography for the analysis of natural waters has been presented by Hites and Biemann (1972). They analyzed a crude solvent extract of a river water. The gas chromatogram (Figure 2A) shows only relatively small, resolved peaks, superimposed over a large background. The latter results from the overlapping signals due to the almost simultaneous elution of many components. It is a typical feature of gas chromatograms of complex mixtures. Incidentally, the chromatogram of Figure 2A has

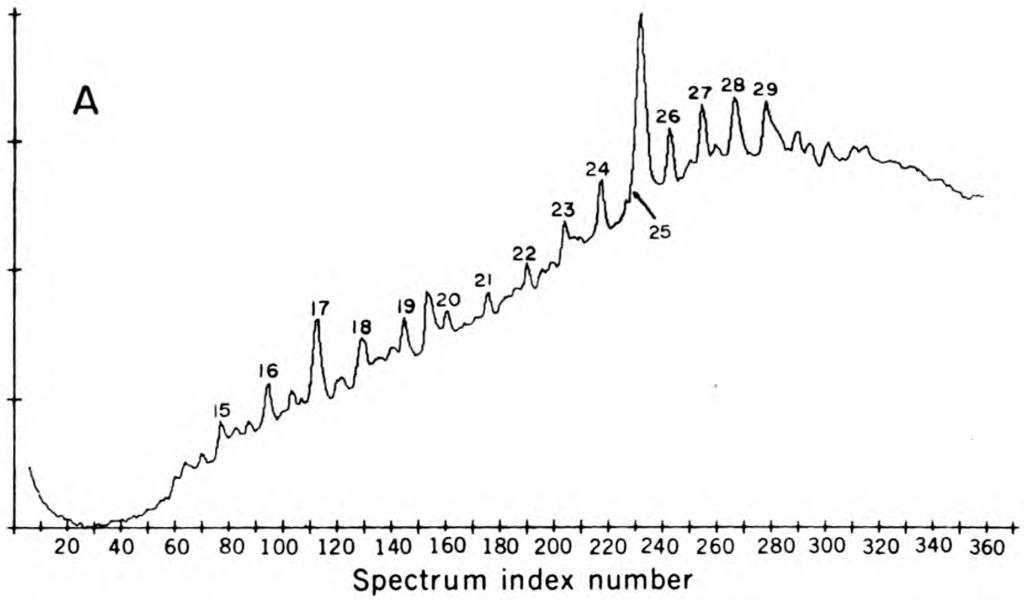


*Figure 2A — Gas chromatogram of a river water extract, as reconstructed from the memory of a continuously scanning GC/MS/computer system.*

also been reconstructed by the computer through integration of the intensities of all ion fragments in every one of the spectra. The *mass chromatogram* for ions of m/e 99 ($C_7H15^+$), resulting from n-alkanes in Figure 2B, exhibits, relative to the gas chromatogram, a "cleaned-up" display of the alkanes. The presence of n-paraffins in the $C_{15}$ to $C_{31}$ range is clearly established and the distribution pattern of these straight-chain hydrocarbons displays interesting features that were not readily apparent in the original gas chromatogram.

This distribution pattern can be interpreted directly as a result of several source contributions; the two principal sources of n-alkanes are suggested by the pronounced bimodal molecular-weight distribution. The $C_{15}$ to $C_{21}$ range coincides with that of distillate fuel oils. The upper envelope ($C_{21}$ to $C_{31}$) contains alkanes that are formed in small amounts by algae and possibly by some bacteria. Other minor contributions are evident. Heptadecane ($C_{17}H_{36}$) and nonadecane ($C_{19}H_{40}$), the outstanding peaks in the lower envelope, are common and abundant in algae. A slight predominance of the odd carbon-number alkanes $C_{27}$, $C_{29}$ and $C_{31}$ over the smoothed curve of their even carbon-number homologues suggests a contribution either from terrestrial plant waxes or from soil, in which these hydrocarbons predominate.

It is remarkable that a clear picture of the alkane distribution pattern in the river water can now be obtained without the previously required and time-consuming isolation of the saturated hydrocarbons by liquid chromatography.

Hites and Biemann searched the computer memory for the presence of other compound classes, such as alkylated aromatic hydrocarbons

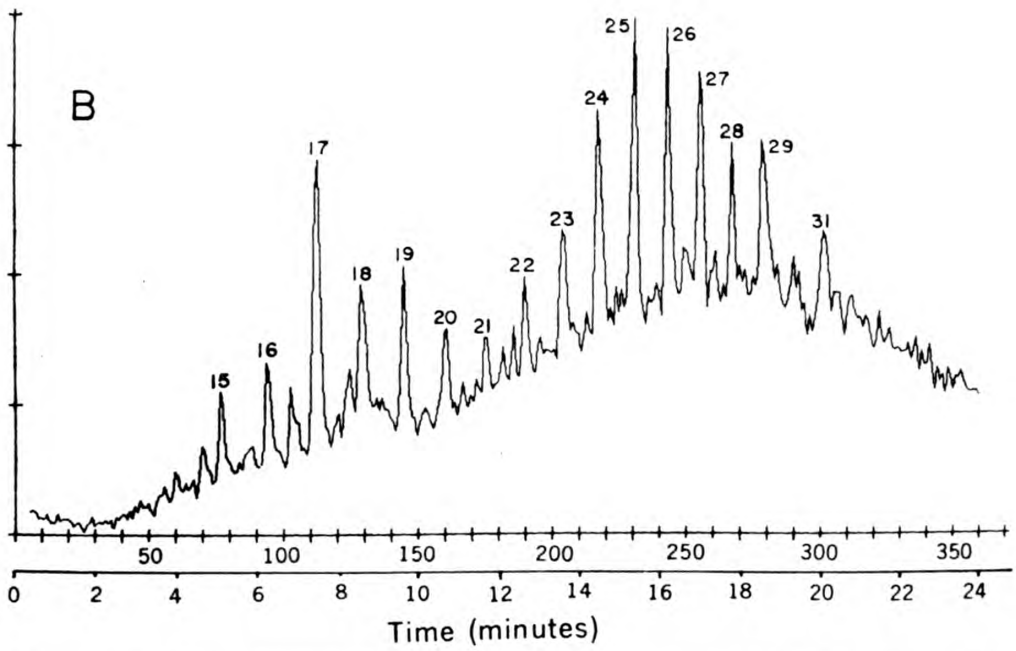


*Figure 2B — Mass chromatogram (m/e 99, $C_7H_{15}^+$), corresponding to the gas chromatogram in 2A. Numbers refer to the chain length of normal alkanes. (Figure 2 from Hites and Biemann, 1972. Copyright 1972 by the American Association for the Advancement of Science).*

and phthalate esters. Again, the presence of these compounds can be interpreted in terms of the different sources which contribute organic material to the river water.

Some compound classes, such as halogenated pesticides, produce highly specific fragment ions and can be recognized in complex mixtures at concentrations where direct gas chromatographic identification is difficult. In these cases, the computer-interfaced combination of gas chromatograph and mass spectrometer becomes a set of new specific gas chromatography detectors, supplementing those available in the past.

I have singled out mass chromatography as a particularly powerful and adequately sensitive tool to deal with the low concentrations of many organic compounds in sea water, sediments and organisms. Other techniques of instrumental structual analysis, such as infrared and nuclear magnetic spectrometry, are complementary to mass spectrometry, but the conventional instrumentation has lacked in sensitivity. In both areas the sensitivity can now be raised by several orders of magnitude through computer processing of the spectral information, either by time averaging or through Fourier transform spectrometry.

The new techniques represent basic developments in the spectrographic art. Though developed without direct concern for the marine sciences, they have great potential in this area; yet, in spite of the promise, applications remain to be made. The following brief comments

suggest a similar gap between research potential and marine applications not only in analytical technology but in basic scientific thought.

## Marine Organic Polymers

One of the principal aims of marine organic chemistry is to achieve understanding of the complex composition of sea water and marine sediments as the result of contributions from many sources and processes. Organic compounds are being isolated and their structures are studied principally to retrieve information about their origin, though the chemist may also derive satisfaction from succeeding in a particularly difficult analytical task.

So far, the major effort in the organic field has concentrated on only a minor fraction of the constituents: those compounds of relatively low molecular weight which are sufficiently soluble or volatile to yield to conventional analytical chemistry. However, quantitatively, the higher molecular weight components far outclass the smaller entities, and it is likely that they carry far more information about source materials and environmental processes.

In terms of their origin and composition, the marine polymers span a wide range. Generic names (fulvic and humic acid, gelbstoff, kerogen, *etc.*) are used because we lack detailed chemical insight into their composition. These names do not imply a specific structure or structural homogeneity within each class. Fleeting transitions may exist between different types of marine polymers and between the different molecular weight fractions. Analytically, the most demanding task is the structural elucidation of the high polymers. Yet it is quite likely that many of their structural features, except for a high degree of crosslinking, may be mirrored in the structures of the low and intermediate weight polymers. Because of their greater solubility and less condensed structure, these may yield more easily to physical separation and to mild degradation.

The marine polymers comprise a dynamic and variable system. An interesting aspect of their sequential chemical changes with time lies in the transition from well-ordered biochemical structures, built with metabolic energy, to more randomized molecules in sea water and younger sediments, and eventually, following the demands of thermodynamics, again to ordered structures in old sediments. This transformation reflects the principal processes which form and transform polymers in the earth's upper crust. Conversely, information on these processes is encoded in the chemical structures of the slowly transforming polymers. In their elucidation lies much promise for a more thorough understanding of marine and sedimentary chemistry. I believe that the background knowledge to achieve this understanding exists in polymer science.

Polymer chemistry is an important branch of organic chemistry with many applications in molecular biology and polymer technology. Life is based on the information encoded in polymerized amino acids, nucleic acids, and carbohydrates; and the large-scale production of synthetic polymers has transformed our way of life during recent decades. Certainly, our understanding of life and the large scale production of synthetic polymers would be impossible without the present basic knowledge and tools of polymer chemistry. These fields—and polymer chemistry—have grown in mutual response to each other. Surprisingly, in marine and geochemistry, where polymers play an equally important role, the tools and the thinking of the polymer chemist have hardly been applied.

## Hydrocarbons in the Sea

Not too many years ago the study of hydrocarbons in the sea was neglected and appeared to contain little scientific challenge. Since then it has evolved into a field of considerable academic and practical interest. In part, the discovery of complex hydrocarbon assemblages in most marine organisms and, in part, the present concern about the fate and effect of fossil fuel pollutants have been responsible.

For the chemical oceanographer much of the interest in this area centers on the great variability of the hydrocarbon composition between different biochemical, sedimentary and industrial sources. These differences reflect different modes of formation: biosynthesis by different pathways in marine plankton, reworking in recent sediments, and slow nonbiological changes in deeply buried sediments. Our discussion of mass chromatography has shown how the hydrocarbon composition of a natural water can be interpreted in terms of its source contributions.

The potential of such studies and the scope of their application depend on the completeness with which we understand the composition of various sources of marine hydrocarbons. Much of this knowledge exists. The hydrocarbon chemistry of marine organisms has been explored by marine chemists; though there are many gaps, several principal features appear to apply commonly. The much more complex composition of fossil fuels has been a challenging field of academic research and one of practical importance in industry for several decades. As a result we possess an excellent knowledge of the composition of fossil fuels and of their range of structural variability.

Again, what we noted above is confirmed here: there is a considerable delay between the acquisition of basic knowledge and competence in a principally chemical field and its transfer to the interdisciplinary science of oceanography. Often, environmental considerations are made that disregard the complexity and the variability of fossil fuels. Since petroleum consists of thousands of compounds that span a wide range

of stability, physical property, and biological activity, "oil" must not be considered as a single chemical entity. Likewise, little of the research potential which the hydrocarbon field holds for the study of oceanic processes has been realized.

## The Gap Between Basic and Interdisciplinary Science

These samples suggest that considerable research opportunities in the interdisciplinary sciences have arisen from the rapid growth of related basic fields. It appears that the transfer of basic information and research techniques to oceanography and to geochemistry is rather slow, perhaps too slow. This may be due in part to the increasing specialization of basic science, to the divergence of language, and to the complexity of modern instrumentation. It has become difficult for a specialist, such as a polymer chemist, to visualize challenging research in a field seemingly as remote as oceanography; it is also difficult for an oceanographer to address the proper specialist in a quest for help (and to speak his language). The trend in oceanographic education away from thorough training in at least one basic science does not enhance the interchange between related but divergent fields.

Our interdisciplinary sciences present excellent opportunities for research; moreover, progress in these fields appears critically important for the best use of rapidly diminishing resources. These sciences now have the potential for more rapid growth than during the last decades, simply because much of the necessary development of background has been carried out in related basic fields. In view of the importance of the marine sciences to man, we need to devote a greater effort to the efficient and rapid acquisition of basic information and research tools. We need to review or revise our educational practices to help our students understand the language and the practice of a wider range of basic sciences.

## References


Aczel, T. and H. E. Lumpkin, "Detailed Characterization of Gas Oils by High and Low Resolution Mass Spectrometry," *American Chemical Society,* August 1972 meeting, Preprints, Petroleum Division p. F 66-80.

Hites, R. A. and K. Biemann, "Water Pollution: Organic Compounds in the Charles River, Boston." *Science* **178,** 158-160 (1972).

# On Naval Research Reserve

### Weekend Seminar Held at Monterey

On 31 March 1973 a Reserve Symposium on "Countering the Soviet Submarine Threat" was held at the Naval Postgraduate School, Monterey, California. This symposium was organized by NRRC 12-8 at Monterey with assistance from NRRC 12-3, Sunnyvale. 254 reserve officers from 42 reserve units attended the symposium.

The program was organized by LCDR Robert Bourke, USNR, NRRC 12-8, an Assistant Professor of Oceanography at the Naval Postgraduate School and a submarine expert. Professor Bourke addressed the group on Soviet Vessels. The other morning speaker was Professor Donald C. Daniel of the Naval Postgraduate School, speaking on Soviet Strategy. The afternoon speakers, on Tactics, were CAPT Thomas Wentworth, USN, Commander Fleet Air Wind TEN; RADM Carl J. Seiberlich, USN, COMASWGRU THREE; and CDR Harold Mathis, USN, Commanding Officer, USS SCULPIN (SSN-590), speaking on their own areas. The speakers were outstanding, giving this very diverse audience an excellent picture of the most current problems and current solutions to the ASW problem.

### Weekend Seminar on "Marine Resources"

NRRC 8-3, College Station, Texas presented a 3-day seminar on "Marine Resources" aboard the Texas Maritime Academy training vessel SS Texas Clipper in Galveston, January 5-7, 1973.

Among those speaking included Dr. Albert R. Dawe, Deputy Director and Chief Scientist of ONR Branch Office, Chicago. Forty-four Naval Reservists from 14 cities in Texas and Louisiana were in attendance for the three-day seminar.

Speakers were noted authorities in marine resources:

Dr. Ernest L. Kistler, Assoc. Professor of Marine Sciences, Texas A&M University on "Models for Ship Design".

Dr. Edward L. Beckman, Chief of Maritime Medicine Division, The Marine Biomedical Institute, Galveston, Texas on "SEALAB II and TEKTITE I".

Dr. William Fife, Assistant Director of the Texas A&M Institute of Life Sciences and professor of biology, "Deep Sea Diving Technology".

Dr. Dawe spoke on "Present Research Sponsorship by the Office of Naval Research".

Berthing and meals were provided aboard the SS Texas Clipper, operated by Texas A&M University's College of Marine Science and Maritime Resources.

A similar seminar on water and air pollution is being planned for January, 1974. Details will be published when speaker committments and arrangements are finalized.

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## Observations of Galactic Cosmic-Ray Intensity of Heliocentric Radial Distances of From 1.0 to 2.0 Astronomical Units

Using a large body of data for the period 1937-1952 from a worldwide network of ionization chambers, Forbush demonstrated an 11-year cyclic variation of the intensity of galactic cosmic rays. The correlation with sunspot numbers was negative; *i.e.*, the maximum cosmic-ray intensity occurred near the time of minimum solar activity and vice versa. The prevailing interpretation of this solar-cycle modulation attributes it to the composite of convective-diffusive-accelerative effects of the interplanetary magnetic field carried by the solar wind. It remained to determine the amplitude of the modulation as a function of heliocentric radial distance r, and ultimately to determine the absolute intensities and energy spectra of the various constituents of the galactic cosmic radiation outside the solar system. Previous attempts in this direction over the range from 0.9 to 1.57 a.u. (1 a.u. = 92.9 million miles) have led to a bewildering array of conflicting findings.

Professor James Van Allen, with the support of the Office of Naval Research, attacked the problem with University of Iowa instruments on the spacecraft *PIONEER 10* enroute to a fly-by of Jupiter. Two small Geiger-Muller tubes in instrument are heavily shielded over 4 $\pi$ steradians and have an effective energy threshold for protons of approximately 80 million electron volts, a sufficiently high energy to reduce the contribution of solar-emitted protons to a negligible value except during periods of a few days duration following certain energetic solar flares. Daily average counting rates of these detectors were correlated with data from *EXPLORER 35* (in orbit around the moon) and with ground-based neutron monitors. Since *PIONEER 10* reached a value of 186 million miles only 137 days after launch in 1972 the briefness of this period tended to minimize the coupling between time variations and radial variations. This period included short-term "Forbush Decreases" of typical time profile as follows: on March7, −3.9 percent, on April 23, −3.1 percent; on May 15-16, −3.9 percent; and on June 17, −5.0 percent.

From these observations it is concluded that the integral intensity of the galactic cosmic radiation of approximately 80 million electron volts varied by less than 3 percent (either plus or minus) over the heliocentric radial range 1.0-2.0 a.u. during the epoch 1972 March-July.

This study is continuing as *PIONEER 10* continues its trip to Jupiter and the heliocentric radial distance increases.

# Research Notes

## More History on SKYHOOK

As an addendum to an article in the February issue of *Naval Research Reviews* is printed the following letter from Larry Booda, Editor of *Undersea Technology,* which provides additional facts on the early days of SKYHOOK

"Twenty-Five Years of SKYHOOK" by CDR Ed Melton in the February, 1973, issue of *Research Reviews* aroused some memories. During the early period of the program (1946-48) I was a reporter for the Minneapolis Star and flying in the Naval Reserve at Wold-Chamberlain field.

After the initial experiments by ONR and General Mills proved the plastic balloon concept Dr. Frank Oppenheimer, research assistant at the University of Minnesota, and, like his better known brother, a physicist, became interested in the payload capabilities of the SKYHOOK balloons. He wanted to send a cosmic ray detecting cloud chamber aloft. The chamber he designed fitted into a basketball sized container. Essentially, it was a cubic shaped airtight box, which, on reaching altitude, periodically induced a partial vacuum, creating a fog, or cloud. At the same moment a stroboscopic flash was discharged and a camera took a picture which revealed the telltale paths of the cosmic rays blasting atoms apart, scattered particles along diverse paths.

With little funding, Oppenheimer arranged to send payloads aloft with the balloons. But there was the problem of tracking. He appealed to the Naval Air Station. The reply said that if volunteer reserve pilots could be found the expenses could be written off as enhancing their proficiency. Fortunately, I had a flexible schedule and was able to trade days off with other reporters. I became chief cosmic ray pilot.

The first SKYHOOK-cosmic ray flight took place March 23, 1948. (My official logbook can be credited for these exact data.) The aircraft was SNB-2 BuNo. 51064, an old Beechcraft bomber trainer with a big transparent plastic nose. Dr. Oppenheimer and an assistant took their places in the nose section while the copilot, LT Ginsburg, and I occupied the cockpit area.

Launching was scheduled to take place from Camp Ripley, 65 miles northwest of Minneapolis, near the town of St. Cloud. We arrived on time and the balloon was launched. We climbed with it to 8,000 feet, then leveled off, using only enough power to stay in the air. The balloon continued up, with four pairs of eyes watching it. At 90,000 feet it appeared to be a planet, like Venus or Mars. An internal timer released the parachute, whose shrouds held the cosmic ray canister.

Meanwhile, we had been transmitting the balloon's position as it criss-crossed mid-central Minnesota. Colleagues of Oppenheimer's were in a station wagon following our directions. The car sported a

brightly marked roof so we in the air could spot it easily. The crew reported later that it was weird to have a voice emanate from the receiver on the back sea, telling whem where to turn.

On this initial flight we learned one eyeball lesson. When the load was released the balloon envelope rose rapidly and burst spectacularly due to the rapid gas expansion. At the same time the canister descended rapidly with the parachute only partially inflated due to the rarified atmosphere. The trick was to watch the chute and not the gas bag. Luckily, with four of us watching we kept it in sight. The descent took from 20 to 30 minutes, by my recollection. We directed the ground crew to where it landed, where they retrieved the canister and parachute.

Flights were made March 29, April 21 and May 14. Flights, usually broken into two segments, added up to 3.5 hours. We had learned to fly to St. Cloud first to await the launching, which, due to winds, could be delayed.

There was one exception to the pattern. The April 21 flight went off on schedule. When the release time came, with the balloon at 90,000 feet, nothing happened. We continued to track the balloon, which wandered over through middle-northern Wisconsin and the upper peninsula portion of Michigan. Our necks grew tired and our eyeballs ached. Gradually it lost altitude as the gas escaped and the lower winds brought it back toward the twin cities. At the end of four hours we were circling the balloon, broadcasting air navigation hazard warnings.

At this point we had emptied the main tanks and one 25 galloon reserve tank, sucking them dry. LT Ginsburg, a 6 foot 4 inch mountain of a man, a working farmer, suffered more than anyone else. He was cramped into a pilot seat that was designed for a smaller man. Fortunately, there was a relief tube aboard, and we all took advantage of it. The balloon finally came down in a farmer's pond in western Wisconsin. After directing the ground crew, with the gas situation becoming critical, we headed for home, carefully going by St. Paul Municipal Airport. On landing at Wold Chamberlain we did have enough to taxi to the line, being informed later that we had three gallons of gas left after the 4.8 hour flight.

Oppenheimer later offered to pay us to fly a private aircraft, but we declined, saying it was too much fun. Whether the flights continued for this purpose, I don't know, because I returned to active duty to become head of section and Editor of *Naval Aviation News*."

## Navy Initiates Diving Program Using Hydrogen as Breathing Gas

The Navy has inaugurated a research program to study hydrogen as a breathing gas for diving. Five volunteer civilian divers have been engaged in a series of pressure chamber dives which include breathing a mixture of 97 percent hydrogen and three percent oxygen for periods of two hours at a simulated ocean depth of 200 feet.

The dives have taken place in the new hyperbaric chamber complex of Michel Lecler, Inc., Harvey, Louisiana, near New Orleans. The experiment, under the direction of Mr. Peter Edel, is being performed under a contract with the Office of Naval Research with funding provided primarily by the Navy's Bureau of Medicine and Surgery. Special physiological, speech, and behavioral studies are being conducted during the diving program by scientists of the Naval Submarine Medical Research Laboratory of Groton, CT.

The diving program covers a series of 24 dives, with eight using a hydrogen-oxygen mixture, eight on helium-oxygen and eight using nitrogen-oxygen as the breathing mixture. Comparisons will be made of the effect of these various gas mixtures on the same diver-subjects. The decompression tables for the hydrogen-oxygen dives have been specially calculated by Mr. Edel.

Called Project Hydrox II, the series of dives is a follow-up to exploratory dives by animals and men with non-explosive mixtures of hydrogen and oxygen conducted by Mr. Edel in Hydrox I. Since this mixture could become explosive when mixed with room air, a special control system has been specifically developed for the safe handling of the gas.

Helium-oxygen mixtures are now used by the U.S. Navy for very deep diving. Although helium has been used down to a depth of 2000 feet in a simulated (chamber) dive, which is far beyond the Navy's present operational capability of 850 feet, helium does have certain drawbacks. The natural sources of helium gas are limited to a few geographic areas in the world. Transportation of helium could be a serious logistic problem for extensive diving operations at sea. In contrast, hydrogen is present in abundance almost everywhere as a chemical constituent of water. It is therefore conceivable that hydrogen could be produced by electrolysis at any location near the sea.

Hydrogen gas is about half as dense as helium gas, and it should take less effort to breathe it at the high pressures of great depths. At those depths the diver's breathing gas has to be greatly compressed, and this in turn greatly increases the normal density of the gas, making it harder work to breathe.

Only a few experimental dives beyond 1000 feet have been accomplished with animals or human subjects. An impairment of well-being in these dives has been variously described and labeled the "High Pressure Nervous Syndrome" (HPNS). This condition is characterized by tremors plus other effects that decrease the ability of the diver to perform useful tasks. Some investigators feel that HPNS is a direct result of breathing helium gas. The theory has been offered that this effect would be less severe with the use of hydrogen breathing mixtures.

The Hydrox dives are the first manned dives with hydrogen gas since 1948 when a Swedish naval officer, Arne Zetterstrom, made a series of pioneering open sea dives breathing a hydrogen-oxygen mixture. Tragically in a dive to 400 feet Zetterstrom died in an accident not related to the use of hydrogen. This event, however, plus the danger of working with hydrogen has discouraged experimenters from attempting hydrogen dives until recently.

Experiments during Hydrox II include a study of the amount of speech deterioration with hydrogen gas. Helium gas produces the so-called "Donald Duck" effect, and there is some evidence that this voice distortion is no worse with hydrogen.

This experimental series should add greatly to the information on the use of hydrogen-oxygen breathing mixtures and thereby provide a better indication of its potential use in Navy deep diving operations. The data gathered could serve as the basis for further experiments designed to probe the ultimate depth limits for divers with this mixture.

*(Continued from Page 13)*

The workshop gathered together scientists and engineers to discuss a recently noted phenomenon in the mechanical behavior of solids, the "strength differential" (SD) effect. SD refers to the difference that is found between the yield strength in loading under compression and the yield strength in tension. The main objectives of the workshop were to define the areas of agreement and disagreement in research results on the SD and to generate additional research approaches that would further characterize the SD effect.

Our interest in the SD goes beyond its obvious application where increased yield strength under compressive loading is of value, as, for example, in submarine pressure hulls. It extends to improving our understanding of the factors that influence mechanical properties of metals and polymers in the broadest and deepest sense. This requires gaining answers to such basic questions as: "What constitutes the most fundamental relationship between loading and yielding?" and "How do external forces and/or restraints modify plastic flow behavior?"

The meeting began with a summary presented by W. C. Leslie of U.S. Steel Corporation, on the research work pertaining to SD in high-strength metal alloys. A review of the salient points that he covered includes a general finding that the compressive yield and flow stresses in carbon steels run 10 to 15 percent greater than tensile flow stresses. All of the high strength steels investigated show an SD regardless of the structure: martensite, bainite, or Widmanstatten. Quite specifically, in martensitic steels the SD increases with carbon content, remains constant with increasing plastic strain, and decreases with increasing tempering temperature. Maraging steels also exhibit an SD, but one that is noticeably smaller than carbon steels, ranging from 0 to 10 percent of the tensile yield stress. Recently, a strength differential has been observed in high strength titanium alloys, as well as in steels; so the SD is not limited to any one metal alloy system.

F. P. Fletcher and M. Cohen of M.I.T. contributed to the discussion on SD in metal alloys by presenting work on Fe-Ni-C steel. They showed that for the as-quenched and low-tempered ($<250°C$) conditions the SD increased as the square root of the carbon content, increasing from 4 percent of the tensile strain (at 1.15 w/o carbon) to 15 percent (at 0.5 w/o carbon). Under the same tempering conditions, the steel displayed a larger SD at $-196°C$ than 25°C. This behavior could be rationalized by assuming an operative strengthening mechanism at low temperatures which requires overcoming a double-kink Peierls barrier; the activation energy to surmount the barrier is a function of stress normal to the slip plane because of the dilatation during the activation step.

The SD observed in martensitic and bainitic steels, according to J. P. Hirth, Ohio State, and Cohen, stems from severe distortions that form in a lattice of iron containing a dilute concentration of interstitial carbon atoms. However, there are other materials deceptively similar in their mechanical behavior that exhibit an apparent SD because of residual stresses, here the SD disappears with increasing strain. This is the case, for example, with duplex ferritic/martensitic structures. It has been suggested that a continuum-plasticity approach to the strength differential effect may be able to distinguish between a true SD and an apparent SD. Thus, if the activation energy for the deformation rate-controlling step is a function of pressure then a true SD is present. It was noted that the inclusion of a pressure-dependent term in the yield function automatically predicts an SD effect, an even in their present forms, yield criteria cannot predict the correct magnitude for both the SD and the bulk volume change which is expected to accompany the observed SD.

We have a fairly good understanding of the SD effect in polymers, as E. Baer of Case-Western Reserve University noted in his summary. Polymers exhibit two types of yielding phenomena—one is dilatational yielding found in macromolecular solids in which cavitation is followed by crazing normal to the principal stress; the other is shear yielding, also typical of the behavior of metals and inorganic solids. The SD in polymers ranges from 5 to 18 percent at room temperature and is similar in magnitude to metals. Polymers are distinguished by the noticeably strong effect of pressure on mechanical properties. For instance, when a polymer is placed under hydrostatic pressure, the tensile flow stress may be as much as three times greater than the stress at atmospheric pressure. In addition, the fracture processes are markedly influenced by pressure, opening up opportunities for the application of hydrostatic pressure in processing technoloy.

Turning our attention to the importance of the SD to designers, in the traditional applications of structural materials designers have requested measurements of the uniaxial yield strength; the materials engineer routinely obliged him. However, theoretical calculation of this property, a classical goal of materials scientists and engineers, is anything but routine. The recent interest in the pressure effect on uniaxial yield strength in tension or compression has led to a new model calculations of the pressure dependence of yield strength. F. A. McClintock of Massachusetts Institute of Technology (M.I.T.) reported on estimates that he had made based on simple interatomic force laws. Since a pressure variation may arise from a variety of causes in different materials, these approximations serve to indicate those factors which contribute to the plastic flow phenomenon. McClintock's first model employs a hard sphere model for ideal yield strength, and he estimates, in the absence of dislocations or imperfections, the shear stress will produce some combination of lifting one layer of atoms over the other or spreading the layers laterally to allow easier passage of atoms along the matching rows. After examining the first model, McClintock suggested carrying out a critical experiment where a specimen in the form of a tube would be placed under torsion loading to see if shear flow is inhibited by hydrostatic pressure. The second model (with credit to J. W. Cahn at M.I.T.) treats a material whose yield strength is controlled by obstacles

that act as barriers to dislocation movements. The beginning hypothesis is the approximation:

$$Y = Eb/\ell$$

where

Y = yield strength
E = Young's modulus
b = Burgers vector characterizing dislocations
$\ell$ = interparticle spacing

The normalized pressure dependence of the yield strength, derived therefrom, is:

$$\frac{\delta Y/Y}{\delta P/B} = 5\text{-}1/3 \text{ to } 3\text{-}1/3$$

where

P = pressure of the ambient
B = bulk modulus of the material

Similar values for pressure dependence are shown to derive from the first model. McClintock recommended comparing these results with the literature values for polymers, metals, and soils.

J. C. Krafft of the Naval Research Laboratory (NRL) contributed two particularly significant thoughts to the workshop. First, he noted that SD values are normally taken as positive, which naturally follows from the original selection of the tensile yield stress as the basic reference state. Suppose instead that the reference state is changed to reflect the one in which the material exhibits its greatest strength and its simplest possible flow mode, which is, of course, shear under compression loading. Testing in ways to add other mechanisms of deformation, such as using hydrostatic tension to produce cavities, will lead to reduced strength. With this reference state, the SD will then reflect weakening effects and carry a corresponding negative sign. Such a convention is more in keeping with theoretical approaches and, consequently, Krafft proposed that the workshop adopt this new reference state.

Second, he commented that weakening, in the form of easier yielding, may be desirable in designing materials to resist fracture, because they make the plastic zone larger and thereby forestall fracture instability. Where fracture toughness is a property requirement, SD data expressed by the above new convention should be both convenient and valuable. The observation of a high compressive strength would confirm high shear strength. A heightened (more negative) SD effect in a material would have two desirable results—the plastic zone would be larger and the fracture strength higher.

A discussion on Technological Implications of the SD Effect for Polymers and Metals, was led by N. L. Basdekas, ONR/Washington. The need for a new yield criterion to account for the SD was debated. Still more dialogue and better identification of the problem appeared necessary.

A discussion on Critical Experiments of the SD Effect for Metals and Polymers was chaired by F. S. Gardner, ONR/Boston. The SD effect is clearly a true manifestation of the mechanical behavior of metals and polymers and there is need for several kinds of experiments and associated measurements. For high strength metal alloys and steels in particular, there is general agreement on the need for determining the volume change accompanying deformation, but this is more complicated than appears on the surface. Ideally, one would like to determine the dynamic volume change accompanying local yielding, whereas the simpler measurement is net volume change, the difference in before-and-after values, bracketing the deformation step. Determining SD as a function of pressure also appears desirable in metal alloys, though polymers are inherently more responsive to changing pressure.

Polymers are excellent materials for the development of plastic-yielding criteria for compressible solids. In particular, the question of a "permanent" or "transient" volume effect must be resolved in future work. Mechanisms to explain the effect of pressure and the associated SD phenomenon need to be developed. The activation volume approach (Eyring) combined with micromechanical analysis around a defect structure with dislocations or disinclinations should be explored. Polymers are highly viscoelastic materials. Needed research relating thereto includes: the effect of pressure on the controlling mechanical relaxation processes using dynamic, creep, and relaxation measurements; models for the pressure-temperature superposition of yield and fracture processes; and investigations of mechanical hysteresis phenomena with simultaneous measurements of changes in volume.

## Mid-Ocean Dynamic Experiment MODE-1

Six ships departed from Woods Hole Oceanographic Institition in March for one of the largest and most extensively instrumented field experiments ever attempted by the physical oceanographic community to understand and measure an important aspect of the ocean's circulation—the basic mechanics of eddies. These eddies are, in the sea, the counterpart of weather in the atmosphere.

The field experiment, called Mid Ocean Dynamics Experiment (MODE-1), will bring the latest in scientific instrumentation to bear upon exploring and measuring the low frequency (weeks to months), intermediate scale (hundreds of kilometers) eddy motions of the open ocean. The construction of a dynamically correct theory of the open ocean, an essential element in the construction of a general circulation model of the ocean, is one goal of the experiment.

Ultimately, MODE oceanographers believe that understanding the general circulation of the ocean is an essential step toward the rational management of man's planetary environment. Fundamentally, oceanographers see the problems of ocean circulation as linked with those of the atmosphere and that to comprehend either, a coupled ocean-atmosphere model will be required. Such a model must contain the significant physical processes governing the dynamics of the air and sea and the significant interactions between the two fluids. The circulation systems of both air and water are complex and the key processes

occur on a myriad of scales in both time and space. The study of open ocean eddies is believed to be a significant step toward the understanding of the ocean's circulation and its relation to atmosphere.

Oceanographers have been unable to launch this type of experimental program before because of the lack of sophisticated instruments and techniques. However, according to Professor N. P. Fofonoff of Woods Hole, the development of such instruments as bottom pressure guages, SOFAR deep floats, current meters attached to moorings and profilers to measure the speed of water as it changes with depth, makes such an experiment possible.

The existence and importance of open ocean eddies were discovered off Bermuda in 1960 by the British oceanographer Dr. J. C. Swallow who found that contrary to popular theory the ocean's circulation was not smooth with its deep main currents drifting northward slowly but rather it was populated with irregular mesoscale motions or eddies.

According to A. R. Robinson and H. Stommel, Professors of Oceanography at Harvard and M.I.T. and co-chairman of the MODE Scientific Council, "Our present level of knowledge and understanding of the mesoscale motions known as eddy processes is extremely rudimentary. We know of their existence and the general associated scales and amplitude but almost nothing specific of the mechanisms of their production and interaction. Although ultimately in a world ocean model, individual eddies may not be explicitly described, eddy processes must be more broadly understood. Their correct delineation requires an understanding of process; thus, the explicit study of the mechanics or basic physics of eddies is now necessary."

The site of the experiment which will last four months from mid-March through mid-July, lies half way between Bermuda and the Bahamas 28 degrees North, 69 degrees 40 minutes West in an area known as the Sargasso Sea. The site measures 300 kilometers in radius and was selected because it is representative of a typical mid-ocean region, but close enough to the U.S. for convenient logistics.

For the MODE field experiment, a hot line center has been established at the Bermuda Biological Station. The Hot Line Center will be a central gathering place for data collection and for on-going decision making during the experiment.

The program is sponsored jointly by the Office of the International Decade of Ocean Exploration of the National Science Foundation and by the Office of Naval Research.

The group of cooperating scientists in the MODE Experiment represent 16 universities and institutions. They include Woods Hole Oceanographic Institution; National Institute of Oceanography, England; Institute of Geophysics and Planetary Physics, University of California, San Diego; Yale University; Scripps Institute of Oceanography, University of California, San Diego, Harvard University; University of Rhode Island; Atlantic Oceanographic and Meteorological Laboratory, NOAA; Massachusetts Institute of Technology; Draper Laboratory; Columbia University; Nova University; The Johns Hopkins University; University of Hamburg, West Germany; University of Gothenberg, Sweden; University of Hawaii.

Other ships will depart from Beaufort, North Carolina; Kingston, Rhode Island; Plymouth, England; Miami and Ft. Lauderdale, Florida.



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## Woods Hole Geological Collection

The Woods Hole Oceanographic Institution has received grants from the National Science Foundation and the Office of Naval Research in support of a project for updating the W.H.O.I. Geological Collection.

The project, which is under the direction of geologists David Johnson and Alan Driscoll, will ensure that proper curatorial facilities are available to support Woods Hole's expanding geological sampling programs. The programs employ both conventional techniques such as dredging, and new instrumentation like the Giant Corer, which is intended to take long, large-diameter samples of mud from the seafloor.

The Woods Hole Oceanographic Institution's Geological Collection now contains approximately 1200 cores, 8,000 sediment samples from the W.H.O.I.-U.S. Geological Survey continental shelf study, 300 dredge samples, and 100 rock samples collected by the mini-sub ALVIN. This material has been obtained primarily from expeditions within the past 15 years, and has recently been relocated in the new core storage facility at the Institution's Desc Building on Quissett Campus.

Under the new project, the cores are being split and photographed on a routine basis, and will be stored in sealed tubes. The basic data for each geological sample—location, water depth, sample size, and type of material—is being computerized for purposes of rapid retrieval, and will be published as a special report in mid-1973. Using these listings, scientists at the Institution and elsewhere will be able to request descriptive information and sample materials for their investigations.

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**Cover Caption**

*Holographic interferometry reveals shape of growing crystals in solidifying materials.* *See page 1.*

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