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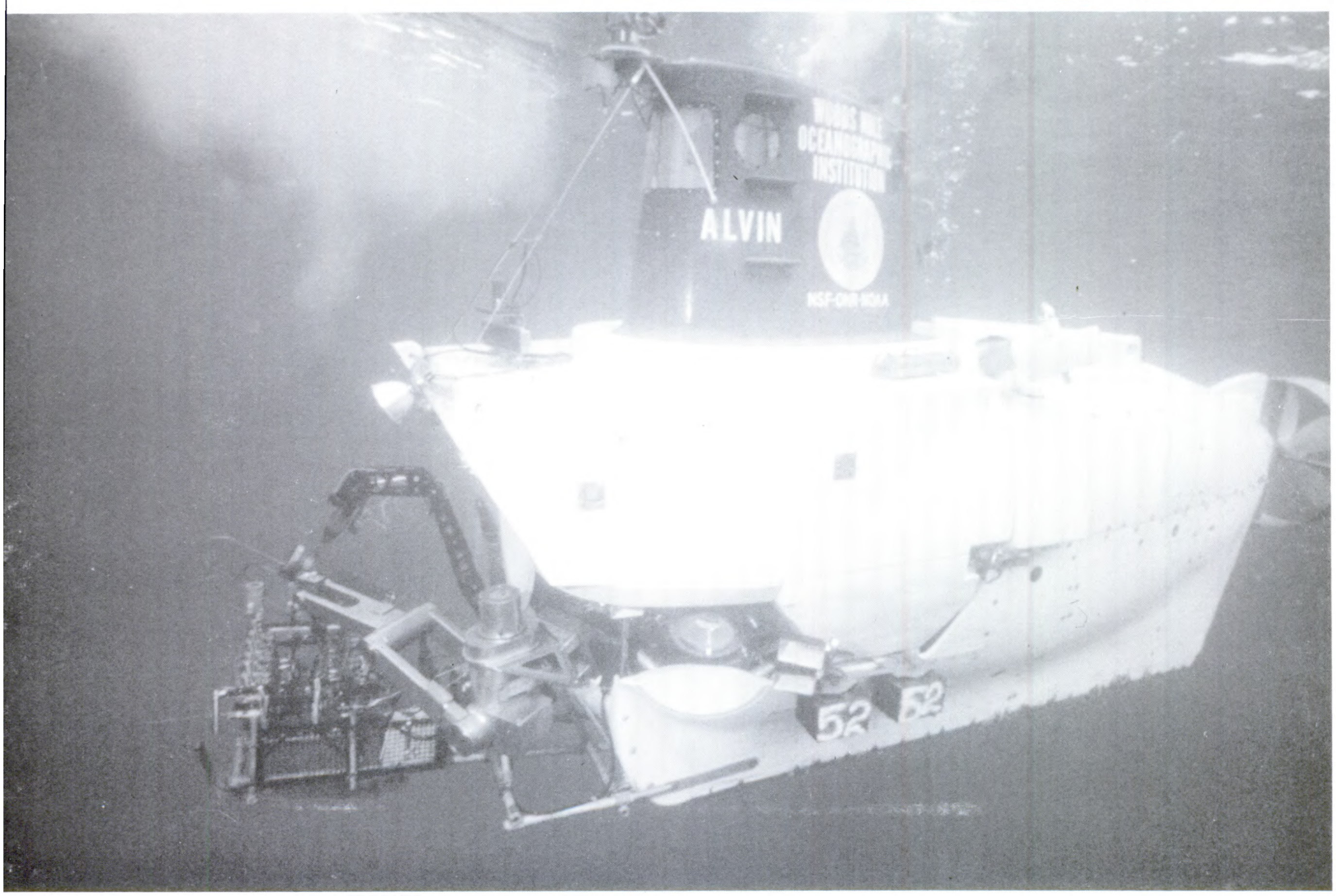
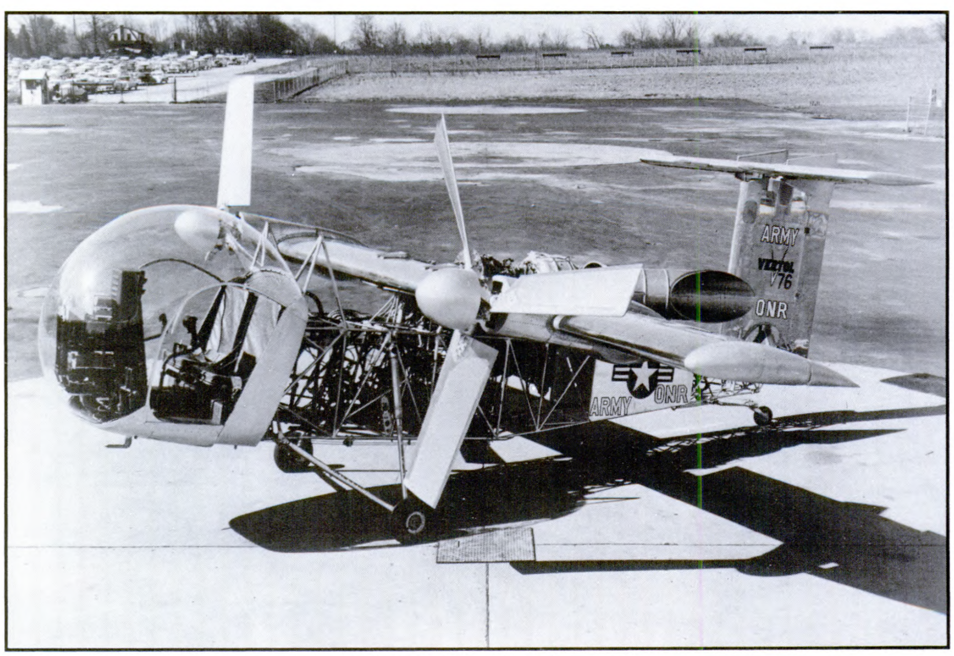


Aircraft with wing tilted

Tilt-Wing Aircraft

This unique airplane was built by Vertol Aircraft Corporation in 1957 for the Army under the technical direction of the Office of Naval Research. This Vertical Take Off and Landing (VTOL) aircraft was designed to take off and land vertically, hover, and fly forward without any ground run. This aircraft is a research milestone in the development of the V-22 "Osprey" tilt-rotor plane of today.



Aircraft with wing down

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Articles

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About the Cover
Alvin descends to the East Pacific Rise with a basketful of hot water samplers.

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Alvin Celebrates 25 Years of Oceanographic Research*

The three-person DSV (Deep Submergence Vehicle) Alvin, which has a depth capability of 4,000 meters (13,124 feet), is a national research vehicle supported by the Office of Naval Research (ONR), National Science Foundation (NSF), and the National Oceanic and Atmospheric Administration (NOAA). The Woods Hole Oceanographic Institution has operated Alvin for 25 years. The nation's first research submersible, Alvin was built by ONR and commissioned at Woods Hole, June 5, 1964. The sub's usefulness for work on the sea floor was proven early when she participated in the search for and eventual location of a hydrogen bomb lost in the Mediterranean off Spain following a 1966 plane collision.

Since that time, as pilots have become increasingly skilled at maneuvering the sub and a corps of experienced scientific users has assembled, the dives have become more and more scientific. Alvin began as a engineering dream with great potential and has become an important oceanographic tool much in demand. Alvin has made 2,150 dives.

Editor

Naval Research Reviews

The story of Deep Submergence Vehicle (DSV) *Alvin* is a 25-year odyssey of exploration and discovery, loss and recovery, and valiant service – first to engineering vision and later to scientific research. The sub was conceived by forward looking engineers and scientists in the late 1950's, with Woods Hole Oceanographic Institution (WHOI) Geophysicist Allyn Vine as a chief proponent. Both moral and financial support were provided by the Office of Naval Research.

Several approaches to acquisition or construction of a research submersible were explored. Ultimately, a design by Harold "Bud" Froehlich, a General Mills electronics division engineer, was chosen for modification to a research submersible. During construction, General Mills sold the division to Litton Systems, Inc., and that company completed the contract at a cost of about a million dollars.

Design specifications called for a submersible certified to operate at depths up to 6,000 feet carrying one pilot and one scientist (two scientists were accommodated in the final design). There were to be four plastic portholes, one in front for the pilot, two on the sides for science observers, and another looking straight down at the seafloor. Lights were needed to work in the dark of the deep ocean, and sonar would aid navigation in murky water. Maneuverability was provided by a large aft propeller and two smaller side propellers. A mechanical arm would allow samples to be placed in a basket attached to the front of the sub. Tanks of oxygen and canisters of lithium hydroxide to absorb carbon dioxide provided two days worth of livable atmosphere within the 6-foot personnel sphere even though most dives were expected to range from 6 to 12 hours. In an emergency, such as entanglement, the positively buoyant personnel sphere could be released from the heavy framework that would carry batteries, ballast, and other equipment. The sub would be in communication with the surface via an underwater telephone using acoustic signals instead of a wire.

* Reprinted from *DSV Alvin*, a commemorative publication on Alvin's 25th Anniversary, Woods Hole Oceanographic Institution, June 5, 1989

The dedication of Alvin on June 5, 1964 at Woods Hole.

Froehlich's original design was known as "Sea Pup," but during construction, the WHOI group working with General Mills in Minneapolis had begun to refer to the sub as *Alvin* – largely in honor of Al Vine, but also in reference to the popular cartoon character Alvin the chipmunk. *Alvin* was christened by Al Vine's wife, Adelaide, before an admiring crowd on the WHOI pier June 5, 1964 (though there were still skeptics who thought a research submersible a waste of money).

Al Vine himself missed the event – he was 18,000 feet beneath the ocean in the Puerto Rico Trench in a new French bathyscaphe called *Archimede*.

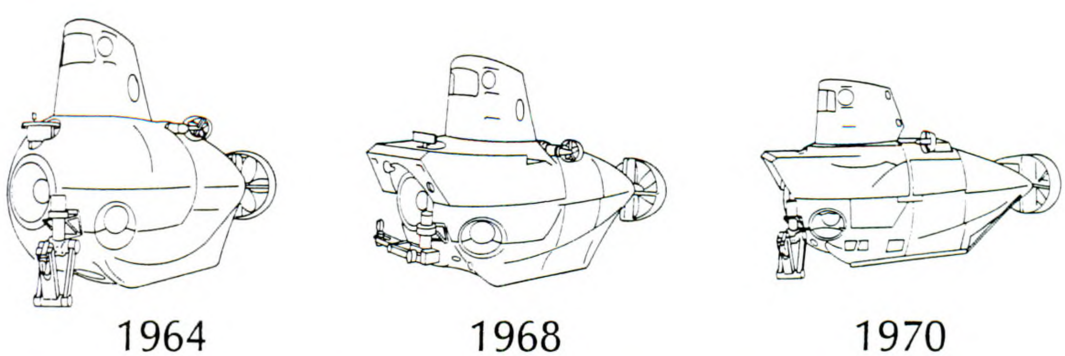
Creation of a mother ship for the sub began when the Navy towed two surplus pontoons designed for minesweeping operations to Woods Hole. Local marine contractor Dan Clark welded two archways to the pontoons creating a catamaran. A bridge was added along with vans to house mechanical electronics, and electrical shops. *Alvin* was lifted from the water by a Holly hoist similar to those found in shipyards. The vessel's power plant and machinery were installed in the port pontoon, and living quarters for 25 were built in the starboard pontoon. The galley was in a trailer on deck. The catamaran was called *Lulu* after Al Vine's mother (a lady, according to Al, "who didn't particularly like ships or the sea, but was happy one of her children did"). Propulsion was provided by a single forward engine, making it necessary for other vessels to tow *Lulu* on nearly every voyage. Two stern engines replaced the single forward engine in 1966 to allow *Lulu* more independence.

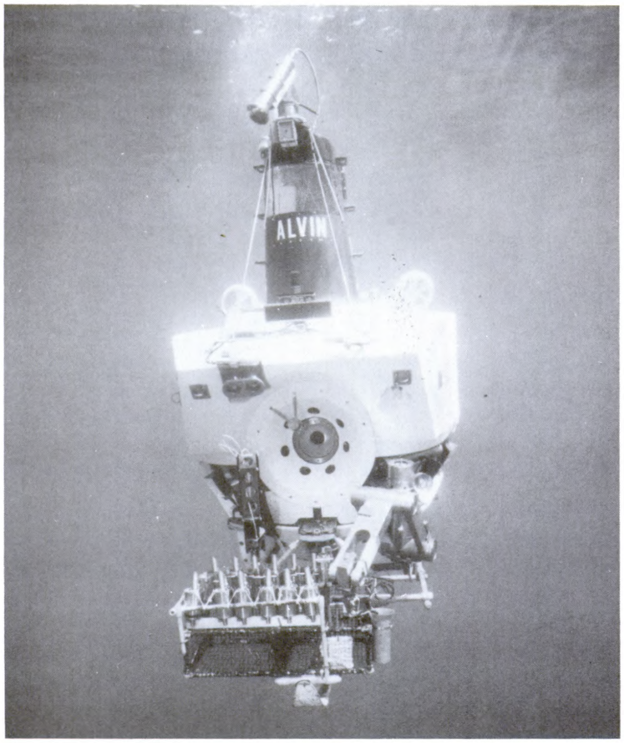
Then the Holly hoise was dismantled and a new elevator platform cradle was built to carry Alvin in and out of the water.

In the three-month operating period of the first year, *Alvin* made 77 shallow dives carrying 54 observers. At the end of the year, the sub was completely dismantled in the first "annual overhaul" for inspection and minor refit in preparation for the first deep dives. On the first of July 1965, *Alvin* was lowered unmanned to 7,500 feet in the blue waters of the Bahamas. A series of increasingly deeper manned dives followed, culminating in a 6,000 foot dive July 20.

The following year, 1966, was to be the first fully operational scientific diving season for *Alvin*. About two-thirds of the sub's time was scheduled for Woods Hole scientists and colleagues, and about two months were scheduled for the Office of Naval Research and other Navy oceanographic

Alvin approches her first mother ship Lulu.





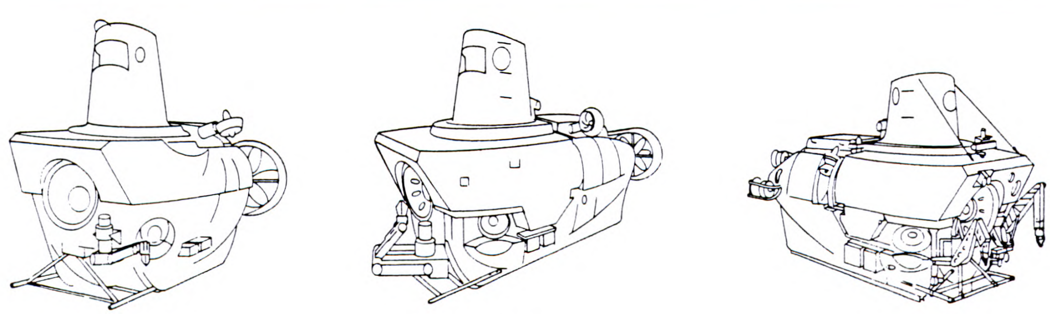
Front view of Alvin under water carrying hot water samplers.

groups. The schedule was drastically altered by the January 17 collision of two U.S. Air Force planes over Palomares, Spain, and the resulting search for a hydrogen bomb lost in the Mediterranean. When the call for help came from the U.S. Navy, *Alvin* was disassembled for inspection and servicing. By the first of February, the sub was reassembled for a flight to the Mediterranean where *Alvin*, the Perry *Cubmarine*, and the Reynolds Metal Company *Aluminaut* were each assigned a hunt site on the rugged seafloor.

On March 15, *Alvin* pilots Marvin McCamis and Valentine Wilson with observer Art Bartlett spotted a telltale trail in the mud at more than 2,500 feet and followed it along a 70-degree slope to the two-by-twelve-foot bomb. With no way to mark it, the tired crew, shivering from the cold, remained on site for eight hours until they could be relieved by *Aluminaut*. This was the first rendezvous of two submersibles at any depth. On the first recovery attempt, a crucial lift line parted after being carried by *Alvin* from a surface ship to the bomb, and the bomb skipped 300 feet deeper than its original position. It took twelve more dives to relocate and rerig the bomb for recovery by CURV (Cable Operated Unmanned Recovery Vehicle).

Any skepticism about the usefulness of a small deep-diving submersible was vanquished by the 34 dives *Alvin* made during the bomb search. The remainder of the 1966 diving season and 1967 found the sub working for a variety of scientific projects and the capabilities of both *Alvin* and *Lulu* slowly improving.

Mother ship Atlantis II recovers Alvin after a dive. Atlantis II is Alvin's second and current mother ship.



1977 1984 1989

View inside Alvin's personnel sphere with a pilot and two observers aboard.

During a rough recovery in 1967, *Alvin*'s mechanical arm was dislodged in a collision with the mother ship, and it plunged to the 4,400-foot bottom. Three weeks later, *Alvin* returned to the spot equipped with a special recovery tray and raised the arm, which was put back into service the following year. Unfortunately, this accident was the precursor to a much more serious loss near the end of the following season. In mid-October 1968, during a routine launch, the two forward cradle support cables broke, and the sub sank in 5,000 feet of water after the three people aboard had scrambled to safety. Unusually severe November weather prevented recovery work that year, but early in 1969 the sub was photographed resting upright on the bottom. After some discussion of simply leaving *Alvin* on the bottom, the recovery advocates triumphed, and the Office of Naval Research asked the Supervisor of Salvage to carry out the difficult task of raising the sub. DSRV *Aluminaut* placed a toggle bar inside *Alvin*'s pressure hull on August 28, and USNS *Mizar* lifted the sub and towed it to Martha's Vineyard for transfer to Woods Hole aboard a barge. After nearly two years of restoration, reclaiming, and rebuilding, *Alvin* went back to work in 1971 with 22 test dives and 40 scientific and engineering dives including establishment of a biological bottom station at 6,000 feet.

Installation of a new titanium personnel sphere in 1973 increased *Alvin*'s depth capability to 12,000 feet, and certification to 13,124 feet (4,000 meters) came in 1976. Project FAMOUS (French-American Mid-Ocean Undersea Study) with French submersibles *Archimede* and *Cyana* brought final full acceptance of *Alvin* as an oceanographic research tool. During Project FAMOUS, scientists had their first close-up look at the Mid-Atlantic Ridge, where two of the earth's great crustal plates are formed as hot lava erupts to create new seafloor and push the plates in opposite directions. The elated scientists returned with 3,000 pounds of rock samples, more than 100,000 photographs, and a better understanding of Planet Earth.

Demand for *Alvin* dives increased. Among the most well-known work in the following years was the discovery of hot vents and their surprising animal communities at crustal plate boundaries in the Pacific (they were later seen in the Atlantic, as well). Work with *Alvin* has uncovered important new information about sedimentation, sediment movement and erosion, deep sea microbiology (initiated by the well-preserved state of sandwiches left in the sub during 10 months on the bottom), and distribution of animals in the water column. The eerie images of R.M.S. *Titanic* were made in 1986 in conjunction with the remote vehicle *Jason Jr.*

In 1983, *Lulu* retired, and R/V *Atlantic II* was converted to serve as support vessel for the sub with installation, among other things, of a hangar for *Alvin* and a giant A-frame for launch and recovery operations. This also provided considerably improved habitation for the pilots and other members of the seagoing support group.

Today's *Alvin* has slowly evolved from the sub christened in 1966. Constant improvements in technology have brought better navigation, greater maneuverability, and increased reliability, efficiency, and performance. The 1,000th dive was made in the 16th year, and the 2,000th came only eight years later.

Early *Alvin* funding came entirely from the ONR, which holds title to the sub. Later years brought major funding from the National Science Foundation and also the National Oceanic and Atmospheric Administration.

Shortly after a major 1989 overhaul and its silver jubilee, *Alvin* begins a new diving season. Tales told at the golden anniversary will no doubt match the adventure, excitement, and importance of those from the first 25 years.

New Horizons in Pulsed Power Research*

Gerald Cooperstein, Plasma Physics Division, Naval Research Laboratory

Introduction

The Naval Research Laboratory (NRL) has established a history of leadership in high-power (10^{12}W), low-impedance (~ 1 Ω), pulsed-power research during the past 20 years. Until recently, the technology has involved primarily capacitive-energy-storage techniques that used closing switches with water as the dielectric-energy-storage medium. In the early 1980's, the development of fast-opening plasma switches at NRL had a dramatic influence on this *conventional* pulsed-power technology. These switches were first used to improve existing generator performance by the addition of a final stage of inductive pulse compression. More recently, they have been used in conjunction with other technologies to develop a new class of pulsed-power generator based on inductive-energy storage techniques that use opening switches and vacuum-insulated inductors. This development has led to a reduction in size over previous generators of one to two orders of magnitude. Based on these results, the Plasma Physics Division, with joint funding from NRL and Defense Nuclear Agency (DNA), is presently undertaking a major multimegajoule upgrade of its pulsed-power, inductive-storage facilities.

History

The NRL Gamble I facility (750 kV, 250 kA, 50 ns), completed in 1968, was called Gamble because it was the first high-power, low impedance facility to use demineralized water as a dielectric-energy-storage medium at high voltage[1]. The main advantages of water as a capacitive-energy-storage medium are that it has a high dielectric constant, is self-healing to electrical breakdowns, and acts as a good insulator for high-voltage pulses of 10-μs duration or less. This technology was pioneered by J.C. Martin of the Atomic Weapons Research Establishment in Aldermaston, England. The initial success of Gamble I led to DNA funding for Gamble II.

The Gamble II generator (see Figure 1) was, when completed in 1970, the largest pulsed-power facility of its kind in the world; it was capable of delivering 1 MV across a 1-Ω load for 50 ns (5×10^{-8}s)[2]. The 1-TW output power was more than the combined electrical power capacity of the United States. At that time, the primary purpose of this newly developed pulsed-power capability was to provide an intense radiation source for simulating nuclear-weapon effects in the laboratory to supplement DNA's (formerly the Defense Atomic Support

*Reprinted from the 1988 NRL Review, Naval Research Laboratory

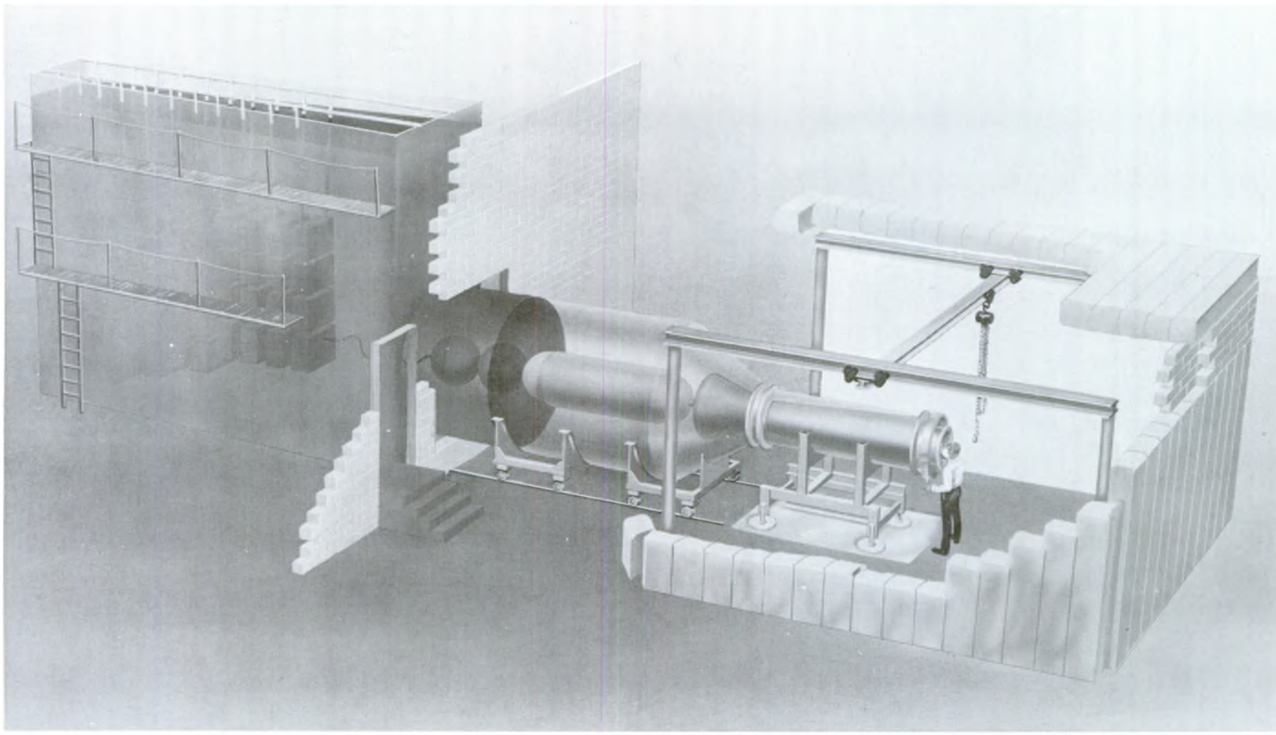


Figure 1

Gamble II is a high-powered (>1TW) pulse generator that uses water dielectric, capacitive-energy-storage techniques.

Agency (DASA)) underground simulation testing program. The intense X-ray bremsstrahlung radiation was produced by generating a 1-MV, 1-MA electron beam in a vacuum diode placed across the generator's output and allowing the beam to hit a high-atomic-number target in a manner similar to a medical X-ray tube. Military electronics were exposed to this radiation to assess their survivability in a real nuclear environment.

Gamble II was the prototype for all modern high-power, low-impedance generators now in existence at private industry laboratories and at both Department of Defense (DoD) and Department of Energy (DoE) laboratories. At present, the largest DoD facility is the Maxwell Laboratory, Inc. (MLI) Blackjack V (2 MV, 5 MA, 80 ns), and the largest DoE facility is the Sandia National Laboratory (SNL), Albuquerque Particle Beam Fusion Accelerator (PBFA) II (15 MV, 6 MA, 40 ns).

Since the completion of Gamble II, NRL has continued to play a pioneering role in the development of the state-of-the-art pulsed-power technology based on capacitive energy storage. Major contributions include the development of:

- electrostatic field plotting and transmission line computer codes for the design of more efficient pulsed-power devices;
- advanced, single surface, plastic insulators to separate the water dielectric from the vacuum diode loads;
- more reliable water switching techniques; and
- triggered oil output switches to replace the final stage untriggered water output switch.

These and other advances led to an NRL-funded upgrade of Gamble II in 1978 that increased the output power to over 2 TW[3]. The upgrade allowed the facility to operate in positive as well as negative polarity so that intense beams of light ions (such as protons and deuterons) could be produced. These ion beams were used for research into inertial confinement fusion (ICF) in a manner similar to the way intense laser beams were being developed to create fusion from small pellets of deuterium and tritium. Today, Gamble II is still one of the world's largest positive-polarity facilities.

Applications

Besides the important nuclear-weapon-effects simulation (NWES) and light-ion-beam ICF research mentioned above, pulsed-power technology based on water-dielectric capacitive energy storage has generated other new areas of research. These types of facilities are now used in industry, universities, NRL, and government laboratories both here and abroad to produce high-power electron and ion beams and soft X rays from z-pinch plasmas, for the general study of matter at high-energy densities for the development of directed energy for the generation of high-power microwaves, for flash X-ray radiography, and for X-ray laser development.

The NRL Gamble research program has trained many leaders in pulsed power that have left the laboratory to assume major positions in private industry, at universities, and other government laboratories. Other scientists have stayed on at NRL to assume leadership roles elsewhere in the Plasma Physics Division in areas of research involving applications of this pulsed-power technology. At present, five Plasma Physics Division branches are all engaged in experimental research involving various applications of this pulsed-power technology. Twenty years ago, no sessions of an American Physical Society or an Institute of Electrical and Electronics Engineers (IEEE) meeting were devoted to this technology or its applications. Today, numerous sessions at professional meetings and several regularly scheduled international meetings are devoted to these subjects. NRL is presently considering hosting in 1992 the Ninth International Conference on High-Power Particle Beams.

The Growing Importance of Inductive Storage Techniques

The successful technology of the Gamble devices and their descendants is based on water-dielectric, capacitive-energy-storage techniques. The cost and size advantages of inductive-energy-storage techniques for pulsed power over conventional capacitive techniques have long been recognized. The key to the development of inductive systems is the advancement of opening-switch technology that, at the terawatt level, invariably involves plasma physics. Research efforts in this area have recently provided new and exciting results. The most important results involve very fast opening (~ 10 to 100 ns) plasma switches, because they can be used immediately to upgrade existing pulsed-power generators by adding a vacuum-inductive-storage, pulse-compression stage for power and voltage multiplication. In the longer term, these new switches, when used in parallel with an additional slower stage of plasma switching (~0.1 to 1 μs opening time), form the basis for a new generation of inexpensive, compact, single-shot or repetitively-pulsed, high-power devices.

Role of Plasma Physics

Although the operation of most opening switches involves complex plasma-physics phenomena, earlier research usually considered the opening switch to be an engineering problem. For this reason, little progress was made in the development of high-power inductive storage until recently, even though inductive storage was first considered 30 or 40 years ago. Examples of the plasma-physics phenomena, which can occur at different stages of operation in such systems, include plasma-wall interactions, electrode sheaths, energetic-particle emission from electrodes, complex mechanisms for electron current conduction across strong magnetic fields, magnetic insulation of electron flows, plasma micro-instabilities and associated anomalous resistivity and plasma hydrodynamics. Plasma physics theoretical tools that can be applied to these problems include kinetic (Vlasov) and fluid analytic treatments, 2.5-dimensional electromagnetic particle-in-cell (PIC) codes, and various fluid and hybrid steel codes. During the past few years, these sophisticated theoretical tools and understanding have been successfully applied to the opening switch operation problem. The detailed understanding arising from the theoretical research, together with recent plasma diagnostic measurements, has provided many of the breakthroughs in opening switch operation and will provide many more breakthroughs. Much of the remainder of this paper discusses this new plasma opening switch technology with emphasis on NRL's pioneering contributions and the way the technology has reshaped, and continues to reshape, pulsed-power research.

Previous NRL Research

Even before these recent breakthroughs in plasma opening switches, NRL was a leader in inductive-storage technology. In 1975, NRL operated a state-of-the-art homopolar generator capable of delivering 3 MJ of pulsed energy to a 1.4-mH inductor and driving pulsed-power loads, by use of opening switches, at peak powers up to 1.6×10^{10}W. This facility was used in conjunction with experimental research involving high-current, capacitor banks, water capacitors, large copper-coil inductors, explosively driven opening switches, and copper-wire and aluminum-foil fuses (used as opening switches) to achieve the first demonstration (TRIDENT I and II) of inductive energy storage at high power[4]. The explosively driven opening switches are now being used by many laboratories in connection with the development of rapid-fire as well as single-shot rail-gun technology. The fuses are an important component of our Pawn facility to be described later. NRL has also made significant contributions to repetitive opening-switch technology by researching electron-beam-controlled switches and phase-transition, solid-state switches. These and other contributions were highlighted when I.M. Vitkovitsky, formerly Head of the Plasma Technology Branch (now Pulsed Power Physics Branch) and then Associate Superintendent of the Plasma Physics Division (now retired), was awarded the prestigious international Erwin Marx Award at the Sixth IEEE Pulsed Power Conference in 1987 for his many contributions to pulsed power research.

A Comparison of Capacitive and Inductive Storage Techniques

A simple comparison of capacitive and inductive energy storage systems is now presented to identify the advantages of inductive systems and clarify the key role played by fast-opening plasma switches in inductive systems.

Simple Circuits

Figure 2(a) shows a simple capacitive-energy-storage system where a high-voltage, low-current primary energy source charges a capacitance C. When the peak voltage V is reached, a closing switch connects the capacitor to the resistive load R_L. The characteristic output duration is R_LC and the peak current is about V/R_L. The prime energy source is high impedance and can be treated as an open circuit after the switch is closed. For such a system, the primary charging voltage is transferred to the load and the current is multiplied by the ratio of the charging time to the output pulse duration. It appears that a high-power, short-duration output pulse could be obtained simply by using a low-resistance output load. Unfortunately, parasitic inductance limits the output pulse rise time to L/R_L for small R_L, where L is the total parasitic inductance, $L_C + L_L$, of the capacitive energy store, the output closing switch, and the load.

For the simple inductive store system shown in Figure 2(b), a high-current, low-voltage primary energy source *current charges* an inductor (i.e., drives the current through an inductor which stores magnetic field energy). When the peak current I is reached an opening switch opens, connecting the inductor to the resistive load R_L. If the load inductance L_L is very much smaller than the storage inductance L, then the characteristic output-pulse duration is L/R_L and the peak voltage is about IR_L. Here, the primary energy source is low impedance and can be treated as a short circuit after the switch is opened. For such a system, the primary charging current is transferred to the load and the voltage is multiplied by the ratio of the charging time to the output-pulse duration. It appears in this case that a high-power, short-duration output pulse could be obtained simply by using a high-resistance output load. Unfortunately, the output-pulse rise time and voltage are limited by the opening time and the voltage hold-off capability of the opening switch. Generally, all that can be expected for a single opening switch is about a factor of 10 for the ratio of switch conduction time (charging time) to opening time (output-pulse duration).

One of the major advantages of inductive systems over capacitive systems is the very high energy densities obtainable with inductors. Capacitive energy densities are limited by the voltage breakdown of materials, whereas inductive energy densities are limited by the mechanical strengths of materials. The energy density in an inductor can be several orders of magnitude larger than the energy density in a capacitor, though present research on advanced capacitors is narrowing this difference. When a vacuum inductor is used, the size of the system can be further reduced because electron flow generated from the cathode surfaces is at low voltage and can be self-magnetically insulated during both charging and discharging. Other advantages of vacuum inductive systems will be presented below when staging is discussed.

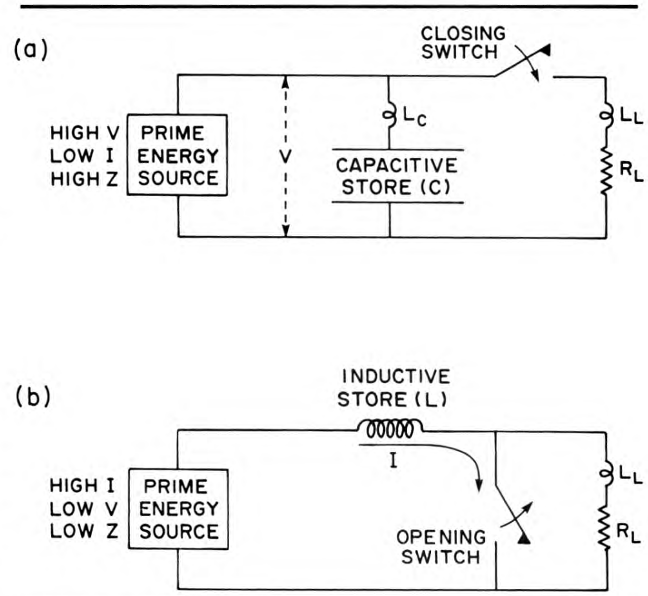


Figure 2

(a) Simple capacitive energy storage system with a closing switch. (b) Simple inductive energy storage system with an opening switch.

Staged Systems

Capacitive and inductive systems, which are more realistic than the simple systems shown in Figure 2, use the staging concept to achieve high-power, short-duration pulses. The rise-time limited problem of finite parasitic inductance in capacitive systems is solved by using several successive stages of lower inductance capacitors connected in series by closing switches to multiply current and power. Figure 3(a) illustrates a typical capacitive system conceptually. A large, high-voltage, low-current, oil-insulated Marx generator, consisting of many capacitors charged in parallel and discharged in series, charges a water capacitor in several microseconds, typically through a triggered gas closing switch. The water capacitor, which has much lower inductance than the Marx generator, then charges an even lower inductance, water-dielectric pulseforming line (PFL) section in a few hundred nanoseconds through a closing switch. This section acts like a simple capacitor during the charging time but acts like a low-impedance PFL while discharging in less than 100 ns through a low-inductance, multi-channel closing switch. Ideally, voltage into a matched load is a square wave with an amplitude of one half the PFL voltage. Voltage (with the exception of the last stage) and energy are preserved, and current and power are multiplied by the successive stages of pulse shortening, Gamble II is good example of a typical, staged, high-power capacitive system.

The finite switch-opening-time problem in inductive systems is solved by using several successive stages of opening switches in parallel. Each stage is capable of conducting current during the longer opening time of the previous stage and then opening in a shorter time to multiply voltage and power. Figure 3(b) shows an ideal, staged, inductive system conceptually. A high-current (>1 MA), low-voltage (<100 KV) source, such as a compact, air-insulated, low-voltage capacitor bank, current charges a vacuum inductor through the first-stage, long-conduction-time switch. A shorter conduction time, faster opening switch is used to provide the final stage of pulse compression and voltage multiplication. The inductance between the two opening switches and the inductance between the final opening switch and the load should be minimized to maximize the energy delivered to the load. Sometimes, as in our Pawn facility to be described later, a closing switch is used to provide isolation between the two opening switches. In the ideal case, the inductor acts like a simple, lumped-circuit element during the long charging time, but acts like a short, current-charged PFL during discharge into the load. The current into a load whose resistance is matched to the vacuum impedance of the inductor is a square wave with amplitude of one half the charging current. Current (with the exception of the last stage) and energy are preserved, and voltage and power are multiplied by the successive stages of faster opening switches.

Advantages of Inductive Systems

Several potential advantages of an inductive system over a capacitive system exist. Both typically have first-stage capacitive storage, but the lower voltage capacitive store of the inductive system is inherently more compact, lighter, and less expensive. The vacuum inductive store has similar size, weight, and cost advantages over the dielectric capacitive store. These advantages increase with the elimination of the storage tanks and associated hardware required for water and oil maintenance in the capacitive system. Also, the voltage across the most critical component in these systems, the vacuum interface, is significantly reduced in an inductive system. In the capacitive system, the full output voltage appears across the vacuum interface. In an inductive system, the vacuum interface sees only the low charging voltage, not the high output voltage. The vacuum interface is physically removed from the load in an inductive system and thus is less affected by ultraviolet radiation and load debris. Even if the vacuum insulator were to flash over when the final switch opens in an inductive system, most of the energy would have already

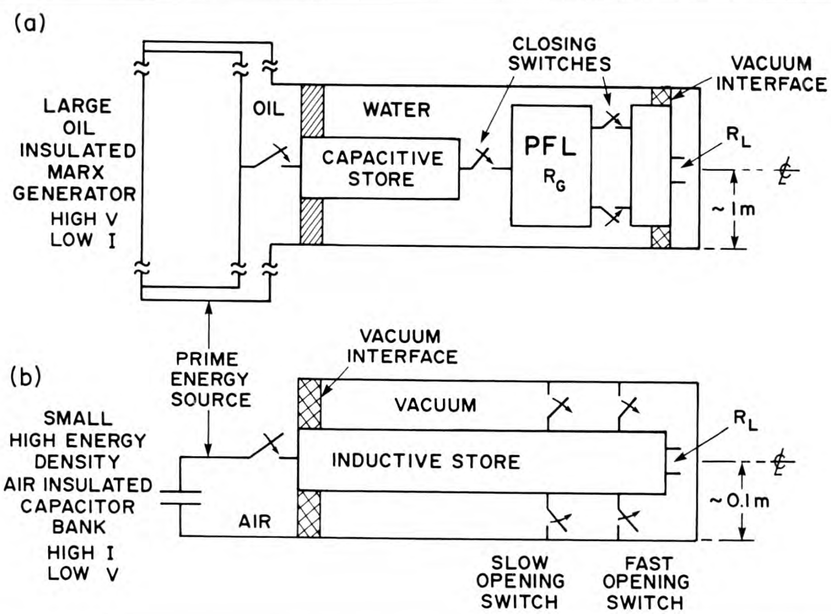


Figure 3
(a) Typical staged capacitve system with successive lower inductance stages in series with closing switches. (b) An ideal staged inductive system with two successive stages of faster opening switches in parallel.

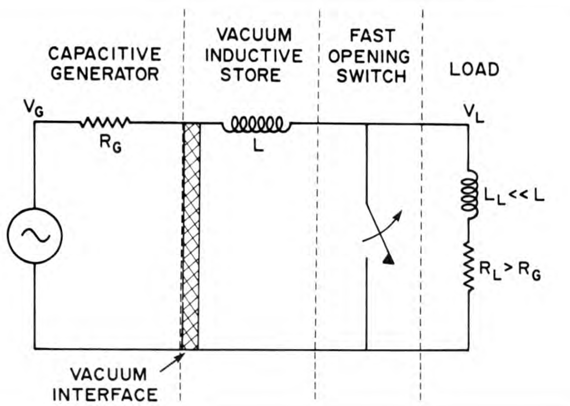


Figure 4

Conceptual circuit diagram of conventional capacitive generator with inductive-store, pulse-compression final stage.

been transferred to the vacuum inductor and thus would be available to drive the load. The staged-vacuum-inductive system conceptually shown in Figure 3(b) has not yet been attempted; however, recent advances in opening switch technology may make this possible in the near future. The NRL Pawn generator to be described later, is a major step in the direction of this ideal system.

Capacitive Generator With Final Stage Opening Switch

Up to the present, much of the opening switch research at NRL has involved the addition of a final vacuum-inductive pulse-compression stage to the output of a conventional, 100 ns, capacitive generator to achieve voltage and power multiplication. In most of the capacitive pulsed-power generators in use today (such as Gamble II), voltage hold-off limitations across the vacuum interface dictate large spacings that, in turn, create large inductances between the coaxial-water-line output and the vacuum-diode load. This inductance is usually the limiting factor in obtaining short output-pulse rise times (<10 ns) at high output powers. By employing this parasitic inductance and an additional vacuum inductance terminated with a fast-opening plasma switch in parallel with the load, it has been possible to obtain short duration, fast rise-time output pulses with substantial power and voltage multiplication. Because the vacuum inductor at the opening switch location can have a small radius compared to that of the water line and vacuum interface but comparable to that of a typical load, the parasitic inductance between the switch and the load can be very much smaller than the equivalent parasitic inductance in the unmodified capacitive system. Thus the output-pulse rise time is primarily limited by the switch opening time. For most plasma opening switches this opening time can be very fast, and the voltage hold-off can be very high because both involve self-magnetic insulation of the electron flow in the switch region.

Figure 4 illustrates the electrical circuit for such a hybrid system. A capacitive generator, with open-circuit voltage V_G and characteristic output impedance R_G, current charges an inductor through a fast-opening plasma switch operating in the closed state. The peak electrical energy stored in the inductor can be greater than 80% of the energy available in the output pulse of the generator. When the current in the inductor reaches its peak, the switch opens and discharges the inductor current through the load impedance R_L. Assuming no energy loss, $R_L > R_G$, and $L >> L_L$, the power and voltage are multiplied by R_L/R_G over the matched load values. This results because the characteristic charging time is L/R_G while the discharge time is L/R_L. Even if the vacuum interface flashes over and becomes a short circuit, the energy already stored in the inductor will be delivered to the load.

Plasma Erosion Opening Switch Research at NRL

As seen from the above discussion, opening switches are the critical elements in inductive-energy-storage systems. For terawatt systems, opening switches must conduct megampere currents, then rapidly switch these currents to loads on timescales short compared with conduction times under megavolt stresses. One opening switch that has these properties is the plasma erosion opening switch (PEOS). NRL pioneered the development of the PEOS as a final-stage, fast-opening plas-

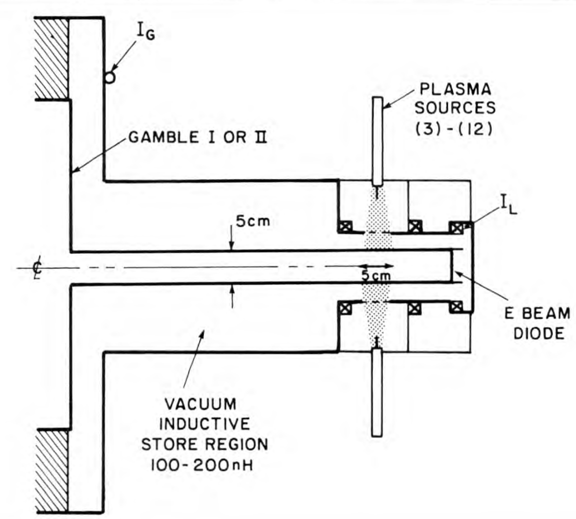


Figure 5

PEOS setup on the Gamble i and II generators at NRL.

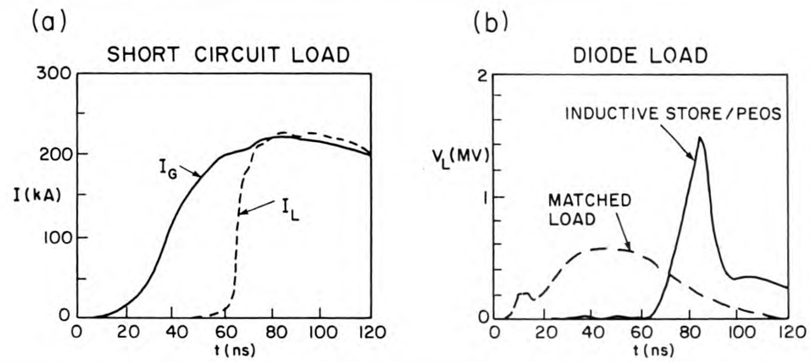


Figure 6

Gamble I PEOS date: (a) measured currents with short circuit load, (b) load voltage and matched load voltage with diode load.

ma switch to enhance the outputs of conventional pulsed-power generators.

A PEOS consists of plasma sources that inject flowing plasmas into the region between the output conductors of a generator. Figure 5 shows a PEOS used on the Gamble I generator. This PEOS configuration is typical of all NRL experiments that use different generators as the current source. A coaxial inductive-energy-storage section is added at the generator output where magnetic energy accumulates while the PEOS is *closed*. The outer conductor in the PEOS region is made of a metal screen or an array of rods. Plasma flows through this outer conductor toward the center conductor, filling the annular region over a limited axial length, typically 5 to 10 cm. A load is located downstream of the PEOS; in Figure 5, an electron-beam (e-beam) diode is shown. The plasma sources are fired 1 to 3 μs before firing the generator so that the plasma bridges the gap between the inner and outer conductors before the generator pulse arrives at the switch. For optimum conditions, the PEOS conducts the generator current as a short circuit, completely isolates the load, opens when a current threshold is exceeded. The switch opening generates a large voltage at the load, and the current is transferred from the PEOS to the load. The PEOS is capable of opening in 10 ns or less and so is able to produce an electrical pulse at the load with short rise time and high voltage and power.

Experiments

In 1977, Mendel et al.[5] reported the first demonstration of opening switch behavior that used an injected plasma on a pulsed power generator. In this experiment, the plasma served to short out the prepulse on the Proto I generator at SNL. The prepulse reduction improved the performance of the diode load by preventing premature plasma formation and impedance collapse. The research effort at NRL and other laboratories followed from this work.

The NRL research effort changed the role of the PEOS from prepulse suppression and rise-time sharpening to power multiplication and inductive energy storage. The ability of the PEOS to enhance the output of conventional generators led to their incorporation in experiments on electron and ion beam diodes and imploding z-pinch loads. PEOS research is continuing in laboratories in the United States, France, Japan, West Germany, and the Soviet Union[6].

The first results demonstrating inductive energy storage, pulse compression, and power multiplication by use of a plasma opening switch were published by Meger et al, in 1983[7]. These experiments were performed on Gamble I. Figure 6 shows typical data from Gamble I for short circuit and diode loads. The plasma conducts the generator current I_G, rising to 200 kA in 50 ns, then opens and transfers current to the load I_L in less than 10 ns. With an 11-Ω diode load, 1.4 MV is generated, over a factor of two greater than the matched load (2 Ω voltage, and the peak load power exceeds the matched load value.

The Gamble I results motivated a concentrated research effort to improve the understanding of the physics of the PEOS and to perform scaling experiments at high current on the 1-MA Gamble II generator. This work was carried out in support of light-ion ICF for DoE and advanced inductive-storage generator development for DNA and the Office of Naval Research (ONR). PEOS experiments on the Gamble II generator demonstrated power multiplication factors of 1.8 at power levels in excess of 2.5 TW[8]. More recent data are shown in the left-hand side of Figure 7. The measured currents, I_G and I_L, are shown in Figure 7(a). The PEOS conducts for 60 ns then opens in less than 10 ns, transferring 770 kA to the load. The output voltage calculated from electrical monitors is noisy (Figure 7(b)) but agrees with the 4.6 MV peak load voltage from a nuclear diagnostic. The matched load voltage in Figure 7(b) shows pulse compression and a voltage multiplication of 2.7. The peak power (3.5 TW) obtained on this shot (Figure 7(c)) is 2.4 times the ideal (zero inductance) matched load

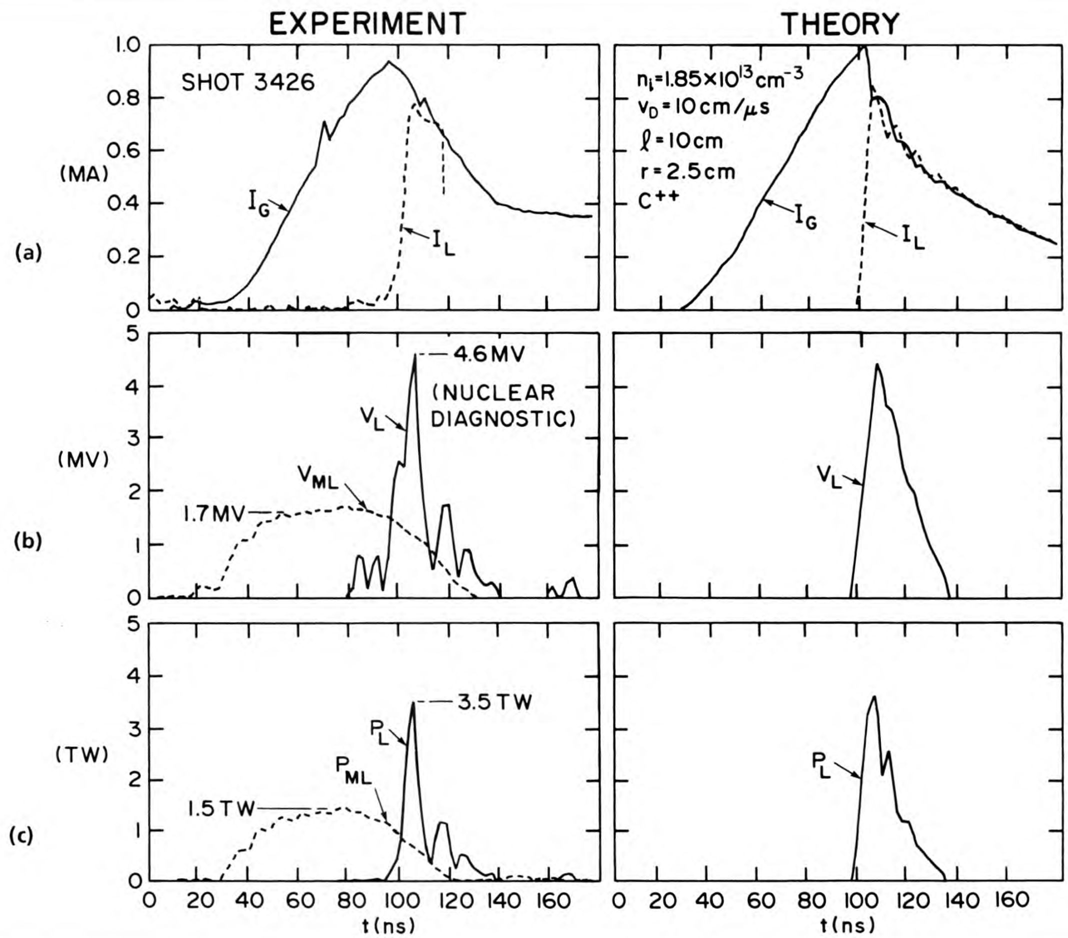


Figure 7

Gamble II PEOS data: (a) generator and load currents, (b) load voltage compared with matched load voltage, (c) load power compared with matched load power.

value with less than 10 ns rise time. These results demonstrate the ability of the PEOS to dramatically enhance the performance of terawatt-level generators. These data are compared to PEOS model predictions (described below) on the right-hand-side of Figure 7.

PEOS experiments at other laboratories began after the successful Gamble results[6]. NRL was given the responsibility of developing the PEOS for the DOE Light Ion Fusion Program at SNL with an eventual goal of halving the pulse width (40 to 20 ns) and doubling the voltage (15 to 30 MV) of PBFA II, the world's most powerful (~100 TW) pulsed-power generator. Experiments up to 3 MA have so far been performed at reduced power levels on PBFA II[9] and PEOS experiments at the 2-MA level were also performed on the 10-TW DNA Blackjack V generator at MLI with NRL collaboration[10].

Theory

The theoretical analysis of PEOS operation is a particularly difficult problem because it involves the multidimensional dynamics of low-density plasmas, space-charge sheaths, high energy electron flows, and excitation of microinstabilities. The large, rapidly increasing electric and magnetic fields combined with these instabilities determine the electron current flow pattern in the plasma during the conduction phase. Complex sheath dynamics with magnetically insulated electron flow controls the opening phase and subsequent switching of current to the load.

A simple theory developed at NRL[11] explains the observed properties of the PEOS as a sequence of four phases. During the conduction phase, plasma ions drift toward the cathode (inner conductor) and electrons are emitted from the cathode and cross a small space-charge sheath to enter the

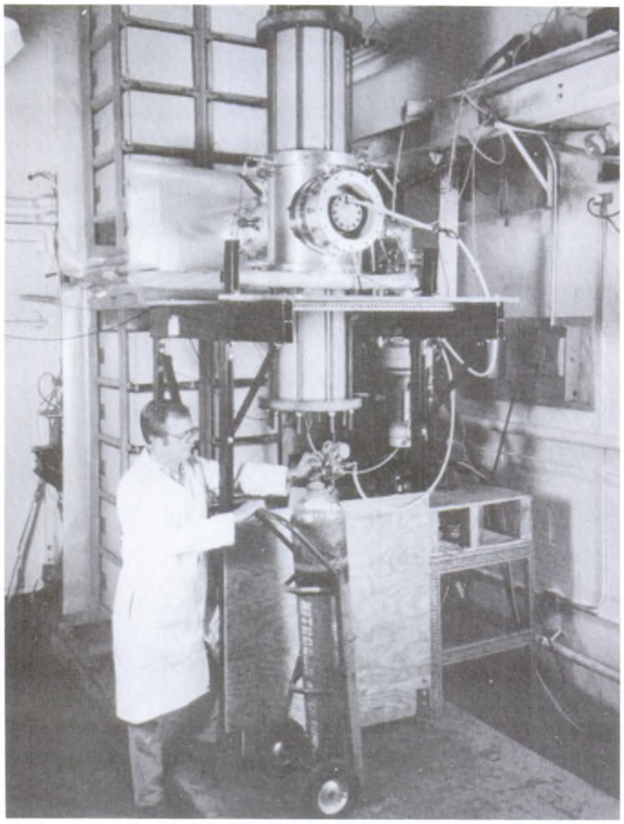


Figure 8

Pawn is a compact 1-MJ high-power pulse genrator that uses vacuum-inductive-storage techniques with two stages of opening switches having fuses and plasmas, respectively.

plasma. The electron and ion current across the sheath are related by the space-charge-limited flow conditions across the sheath that dictates that the current densities are inversely proportional to the square root of their masses. For C^{++} ions, the dominant species, this ratio is 0.01 and the small ion current controls the much larger electron current. As the generator current through the switch increases, the electron emitting area increases since the electron current density is held constant by the constant plasma ion flux. The conduction phase ends when the total cathode area covered by plasma is emitting. This threshold, or conduction current, is determined by plasma density, drift speed, and switch area. The erosion phase begins when the generator current exceeds the conduction current. Ions are collected at the cathode faster than they are replaced by the plasma so the cathode sheath gap widens to uncover more ions. The enhanced erosion phase begins when the sheath gap becomes comparable to the average electron Larmor radius. Under these conditions, the space-charge condition is modified in such a way that the erosion rate is greatly increased. A high voltage is generated across the gap, and a substantial fraction of the current is diverted to the load. The switch is totally open when the magnetic insulation phase is reached. This occurs at a value of current for which the average Larmor radius is less than the gap size so that electrons cannot cross the sheath into the plasma and all the total electron current reaches the load.

The above theory leads to a simple set of equations that form a zero dimensional (0-D) model that has successfully reproduced experimental results under a large variety of conditions. An experiment is simulated by including the PEOS in a transmission-line code as a nonlinear circuit element whose impedance is determined by the equations governing the four phases. This procedure can be used to estimate the effect of parameter changes on PEOS performance and to scale the PEOS to high current and voltage. Examples of this modeling are shown on the right-hand side of Figure 7.

Although the theory described above explains the global electrical properties of the PEOS, it does not treat the physics of electron condition inside the plasma. The spatial distribution of plasma and fields during condition is strongly related to the opening properties of the switch. These processes are beginning to be understood by using the theoretical tools mentioned above. Understanding how the phenomena treated by these analyses affect operation of long-conduction switches is an important ongoing research effort.

Long-Conduction PEOS

The conduction time in the experiments described above is typically less than 100 ns because of the fast-pulsed-power generators used as drivers. The PEOS is capable, in principle, of much longer conduction times. Conduction time approaching 1 μs or longer would be useful for inductive generator systems that use capacitor bank drivers without water-line compression stages. PEOS experiments reported in 1986 from the Soviet Union[12] and NRL[13] demonstrated opening of less than 100 ns, after conduction times approaching 1 μs. The PEOS used in the Pawn experiment described below is based on these results.

NRL Pawn Generator

Figure 8 shows a prototype, compact, pulsed-power generator called Pawn under development at NRL[14]. It uses a high-energy-density capacitor bank (1 MJ, 3 MA, 20 μs at 44 kV) as the prime energy store combined with staged inductive energy storage similar to Fig. 3(b): a fuse and a PEOS are used as the first and second stage opening switches, respectively. The capacitors are discharged into an inductor using *rail gap* closing switches. The circuit is closed with a fuse, consisting of an array of copper wires in a high-pressure gas, designed to explode when an appropriate current level is reached in the

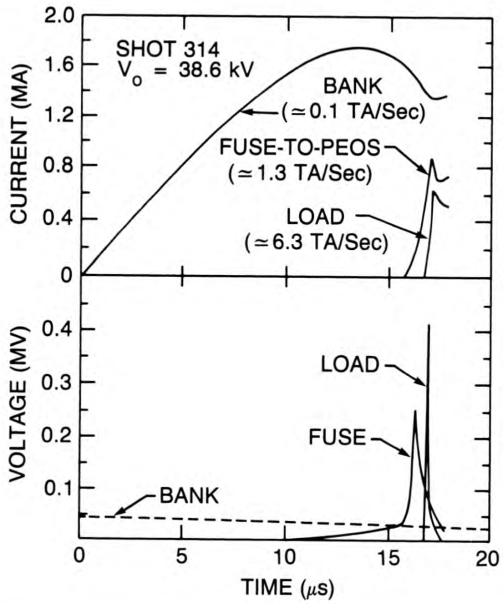


Figure 9

Pawn PEOS data showing current and voltage on the capacitor bank, the fuse, and the load.

inductor. A triggered flashover switch (not shown in Figure 3(b)), between the fuse and the PEOS, is closed during the rapid rise of the fuse voltage. Current then flows through the PEOS, rising to about 1 MA in under 1 μs. The PEOS is designed to open in less than 100 ns and divert the current into a load. The objective is to generate a 1-MV, 1-MA, 100-ns output pulse with Pawn.

Figure 9 illustrates Pawn performance. The capacitor bank current, the current transferred by the fuse into the PEOS, and the current transferred by the PEOS to the electron-beam diode load are plotted together as a function of time. The capacitor bank voltage, voltage generated at the fuse, and voltage of the load are shown on the same time scale. At each stage of switching, the current rate of rise increases (0.1 to 1.3 TA/s, 1.3 to 6.5 TA/s) as does the voltage (39 to 250kV, 250 to 410 kV). The PEOS conducts the fuse output current for 0.7 μs to a level of almost 1 MA before opening and transferring 0.7 MA in about 0.09 μs to the load. The 400-kV load voltage is more than a factor of 10 higher than the initial capacitor voltage. This 1/4-TW output power is higher than that of Gamble I, which ocupies 20 times the volume of Pawn.

With Pawn, we have demonstrated that low-voltage inductive energy storage and sequential opening switches for power conditioning can economically generate high-power electrical pulses from compact generators. Optimizing this system should produce about a twofold increase in the current and voltage delivered to the load. Another area of research consists of developing a very long conduction time (10 to 20 μs plasma opening switch to replace the present inefficient and cumbersome fuse stage. This would also remove the high pressure gas insulators surrounding the present fuse that, in turn, would lead to the ideal, all-vacuum-inductive system illustrated in Figure 3(b). If we are successful, Pawn will provide an electrical power pulse comparable to Gamble II from 1/100 of this volume.

Future Facility Upgrade

The success of Pawn has led us to undertake a major upgrade of our inductive storage facilities. The project, jointly funded by NRL and DNA, will consist of two new inductive facilities – a versatile 3-MJ slow bank called Rook and a lower energy companion device called Hawk. Part of this upgrade also involves the purchase of new data acquisition equipment and diagnostics. With the present Pawn device and the requisite diagnostic capability, Rook and Hawk will give NRL a uniquely flexible, highly instrumented facility. They will be primarily used to support DNA's advanced simulator development program over the next decade by continuing research on both short- and long-conduction-time plasma opening switches and the advanced bremsstrahlung and imploding plasma radiation sources to be driven by this new class of inductive generators.

Hawk

The smaller facility, Hawk, will replace most of the present Gamble I facility while using its Marx tank and oil storage facilities. Physics International Co., Inc. will supply a compact 300-kJ, high-voltage (700 kV) oil-insulated Marx generator that will be used to *current* charge a vacuum inductor to 1 MA in 1 μs. This facility will allow a high data rate of 10 to 20 shots per day compared to 2 to 4 for Gamble II and 1 to 2 for Pawn (limited by fuse replacement).

Rook

The larger facility, Rook, will consist of three 1-MJ, 40-kV Pawn banks supplied by MLI, which will be connected together to charge a common vacuum inductor. With a scaled-up Pawn fuse, it will supply 3 MA in 1 μs at more than 250 kV into a PEOS. More important, without the fuse stage, it will supply over 10 MA in 8 μs at its output for research on very long-conduction-time plasma opening switches to replace the present first-stage fuse opening switch. The development of such long-conduction-time plasma opening switches would allow this new inductive-energy-storage technology to be scaled up to even higher power and energy levels.

Conclusion

The newly emerging plasma opening switches being developed at NRL and elsewhere are already being used to significantly upgrade existing pulsed-power facilities. With further development, these new switches, used in conjunction with recent advances in high-energy-density capacitors, could lead to a new generation of inexpensive, compact, single-shot or repetitively pulsed, high power accelerators that use inductive-energy-storage techniques. Many applications of this new pulsed-power technology are envisioned in areas such as nuclear-weapon-effects simulation, inertial-confinement fusion, X-ray lasers and lithography, neutron radiography, and directed energy weapons.

Acknowledgments

The author acknowledges the many pioneering contributions to pulse-power technology by his colleagues at NRL over the years, only some of which are noted in the references. The author also specifically thanks Drs. P. F. Ottinger, R. J. Commisso, and B. V. Weber for contributing material for this manuscript and, in particular, Dr. D. Mosher for valuable advice during its preparation. Finally, this research effort is particularly indebted to both Dr. S. L. Ossakow, Superintendent, Plasma Physics Division and Dr. T. Coffey, Director of Research at NRL, for their continued support and encouragement.

Biography

Dr. Cooperstein received a B.S. and a PhD in physics from the Massachusetts Institute of Technology. His early work was in generating intense electron beams for simulating nuclear weapon effects. He joined NRL as a section head in 1971, where he was responsible for performing similar research on the newly developed Gamble high-voltage, pulsed power generators (1 MA, IMV, 50 ns). His many publications and presentations have been on the subjects of high-voltage, pulsed power and intense ion beam generation. In 1987, he was elected to Fellowship in the American Physical Society. He is presently head of the Pulsed Power Physics Branch at NRL.

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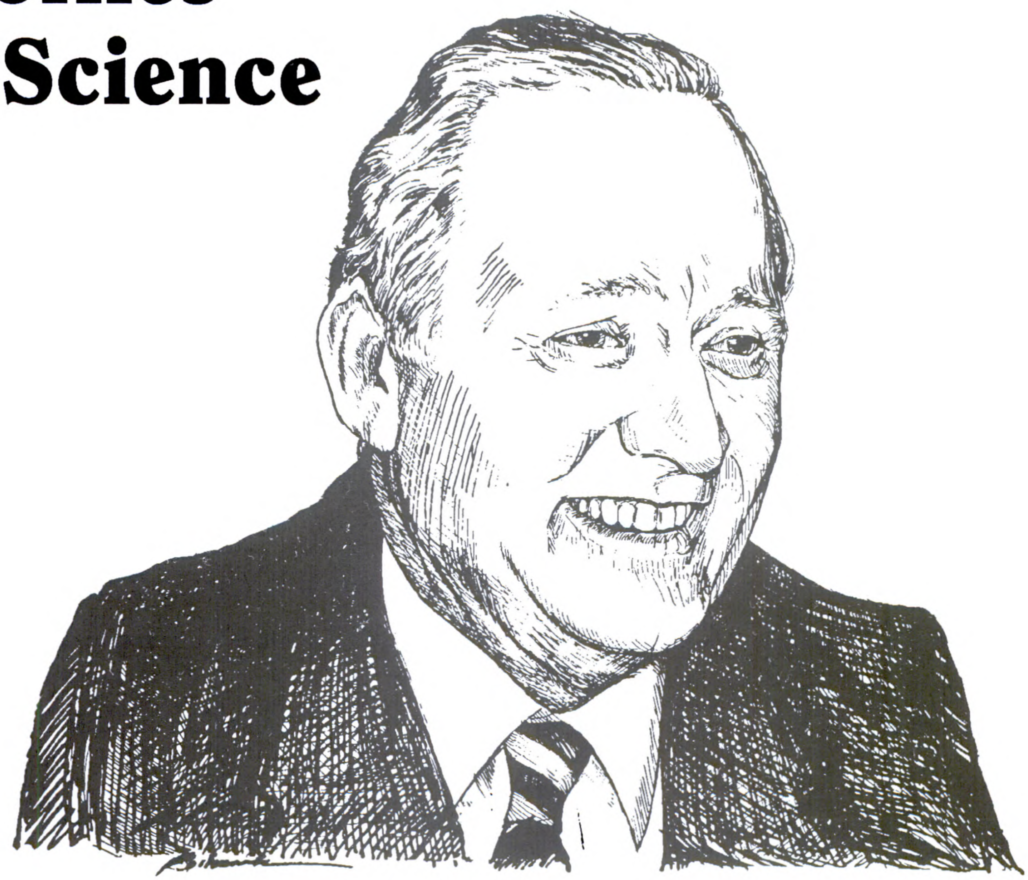
Profiles in Science



Professor Werner C. Rheinboldt is the Andrew W. Mellon Professor of Mathematics and Professor of Mechanical Engineering at the University of Pittsburgh where he has been on the faculty for 10 years. A native of Germany, he received his degrees from the Universities of Heidelberg and Freiburg. In 1956, he immigrated to the United States to work at the National Bureau of Standards and later was on the faculties of the Universities of Syracuse and Maryland.

His research interests are in the general areas of numerical analysis and scientific computing, and more specifically, in the development and study of numerical methods for nonlinear equilibrium problems and the assessment of the resulting computational errors and their control by means of adaptive strategies. Much of this work is motivated by applications in continuum mechanics and especially, by various equilibrium problems. Since 1972, he has been a principal investigator for the Office of Naval Research, working recently in the areas of (1) application of large computational networks and systolic arrays to scientific computations and (2) adaptive approaches and error estimations in finite element applications and mathematical modeling.

Professor Rheinboldt is the author of three books and well over 100 publications in scientific journals as well as being on the editorial board of five scientific journals. He was President of the Society for Industrial and Applied Mathematics and since 1985 has been chairman of the board of trustees of that society. He is a Fellow of the American Association for the Advancement of Science and a recipient of the Alexander von Humboldt Senior Distinguished Scientists Award.

Fourier Transform Raman Spectroscopy

Patrick J. Hendra, The University of Southampton, England

Chemists, physicists and materials scientists, rely on a range of physical methods for analysis. Of these, the most widespread are infrared absorption spectroscopy and nuclear magnetic resonance. Infrared is particularly useful when analyzing solids such as foodstuffs, plastics, rubbers or forensic specimens, yet oddly it is only a partial story. Infrared spectrometry assays the complex vibrations of a molecule and constitutes a 'fingerprint'. However, not all of the vibrations are detected by infrared absorption, many are preferably detected using a rival type of spectroscopy named after its discoverer, Sir. C. V. Raman[1]. This paper aims to show that the Raman technique is set to take its place alongside infrared as a routine analytical method.

Molecular Vibrations

All molecules vibrate continuously and with an almost incredible complexity. Consider carbon dioxide – its unique set of molecular vibrations are as follows:

Vibrational mode ν_1 0 ← C → 0

ν_2 0 ←→ C→ ←0
↑ ↑

ν_3 0 - C - 0
↓

ν_4 0 - C - 0
\+ - +

The vibrations of larger molecules are more complex, but they still describe a unique set of vibrational characteristics which constitute a 'fingerprint' for the molecule. This is very valuable because the frequencies of vibration are easily measured.

If during the progression of a vibration, there is a periodic creation and destruction of a dipole[†], this will resonate with electromagnetic radiation of its own frequency. As energy is absorbed by the molecule, the amplitude of the mode increases. Electromagnetic radiation appropriate to this resonance lies in the infrared, hence those vibrations involving

[†] Unsymetrical distribution of electrons through a molecular system, gives rise to a charge and hence a 'dipole'.

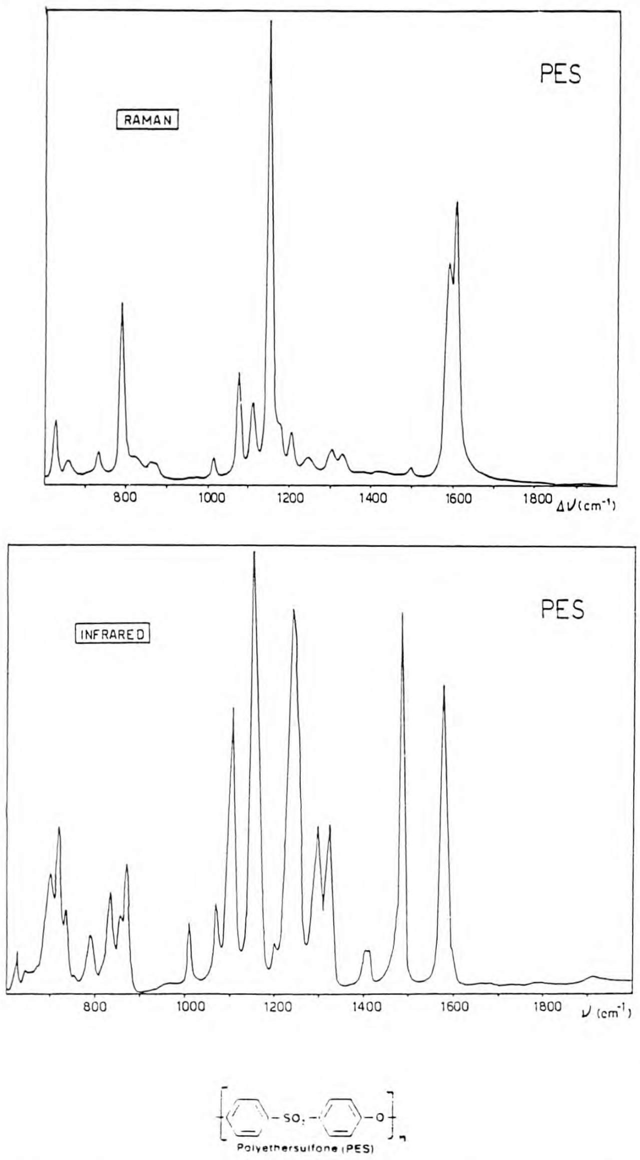


Figure 1

Raman and infared spectra of the same material.

changes in dipole can be investigated by searching for absorptions in the infrared i.e. "Infrared absorption spectroscopy". In CO_2-ν_2, ν_{3+4} are observable in the infrared. Their frequencies are 2 x 10^6 and 7 x 10^6 MHz or in spectroscopic frequency units, 667 and 2349 cm^{-1}.*

All molecules are polarizable, i.e. if exposed to an electric field the electrons will respond by flowing through the system i.e. the polarizability is a measure of a *response* to a field. As vibrations occur, *some* can involve a change in this property. Raman spectroscopy is sensitive to the fluctuation in polarizability. As it turns out, more symmetrical vibrations give rise to the largest changes in polarizability and can be detected by Raman, and the unsymmetrical vibrations give rise to dipole changes and hence infrared absorptions. In CO_2, ν_1 is Raman active. Thus, to acquire the 'true flavour' of the vibrational behaviors of any system it is essential to record both spectra. An example is shown in Figure 1.

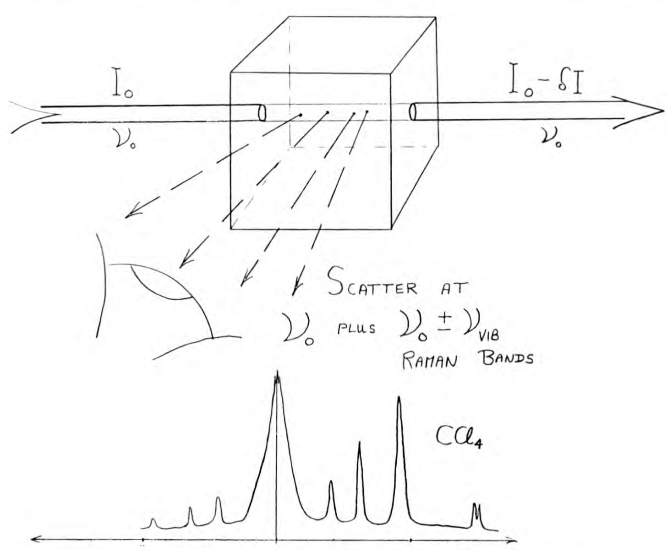
The Raman Process

Raman spectroscopy is an inelastic light scattering process. Injection of monochromatic radiation frequency ν_0 into a specimen results in scattering predominantly at ν_0 accompanied by weak 'side bands' as shown in Figure 2. These side bands are the Raman scattered radiation. To the high frequency side of the exciting line (blue shifted or Anti-Stokes scatter) the intensity of the bands is attenuated, hence Raman measurements are almost invariably taken to the red of the exciting 'line'.

A conventional Raman Instrument employs an intense source (a laser), optics to illuminate and view the sample, a multiple monochromator spectrometer to analyze the scattered

Figure 2

The Raman experiment. Note that red shifted Raman bands are stronger than blue. We therefore scan to the red of the laser line.



* Spectroscopists use the 'wavenumber'. It can be visualized as the reciprocal of the wavelength of the electromagnetic radiation in centimeters.

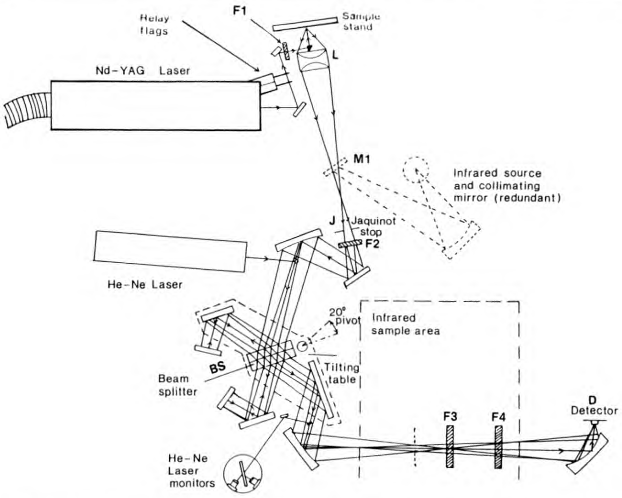


Figure 3

The Southampton/Perkin Elmer Fourier Transform Raman Spectrometer.

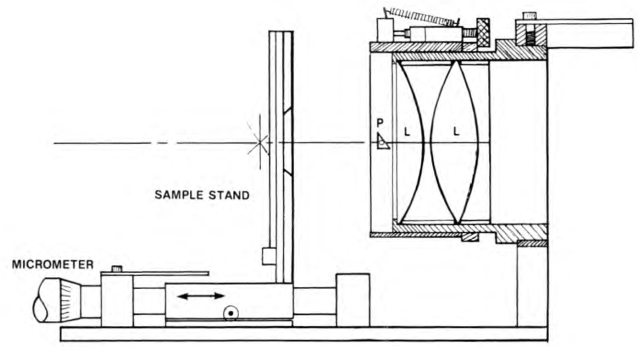


Figure 4a

The sample area of the Southampton/P.E. spectrometer.

light, a sensitive detector system (because the process is weak) and data processing arrangements. Instruments of this type have been available for more than 20 years and can be found in research laboratories all over the world. A readable yet detailed description of infrared and Raman methods is available[2].

Raman Spectroscopy as an Analytical Tool

As pointed out above, it is clear that for diagnostic purposes one should measure both the infrared *and* Raman spectra of a given specimen. Currently somewhere in excess of 100,000 infrared spectrometers are in use. This popularity has arisen because the method is fast (~ 5 minutes/sample) and relatively cheap (several routine quality machines are available at $10,000). Raman spectroscopy, on the other hand, is dogged by several severe problems – analytical samples are frequently colored or florescent, the machines are complex and difficult to run and are expensive (good versatile Raman instruments cost around $100,000, and can cost at least twice this amount!). Colored samples absorb incident light rather than scatter it whilst the florescence process is much more intense than Raman scattering. Almost all impure specimens (i.e. the majority of real analytical samples) are at least weakly florescent. As a result, a *minority* of samples give useable spectra, and industrial analysts obviously lack enthusiasm for a method which they, quite rightly, regard as an expensive oddity. The project described in this article is a successful attempt to bring Raman spectroscopy into the routine analytical laboratory, and hence to lead to mass produced Raman spectrometers of low cost and wide utilization.

Fourier Transform Raman Spectrometry

A few years ago Drs. Bruce Chase of Du Pont[3] and John Rabolt of IBM[4] pioneered a new method of recording Raman spectra. Instead of using a powerful visible laster, they resorted to a near infrared device [Nd YAG running at 1.064 μ] and processed the scattered light using an interferometer. The output data is then Fourier Transformed into a spectrum. Their reasoning was that near infrared sources would minimize the problems of color and fluorescence since most materials transmit radiation in the 1.0 → 1.3μ region, and near infrared photons are unlikely to cause fluorescence. The Raman scatter, now in the 1.1 → 1.7 μ[†] domain is hard to detect because

† 1.064 μ= 9393 cm^{-1}. A Raman shift of 1000 cm^{-1} appears at 8393cm^{-1} or 1.19 μ. The highest vibrational frequencies normally encountered are ~3500 cm^{-1}. This yields a Raman line at 9393-3500 = 5893 cm^{-1} or 1.7μ.

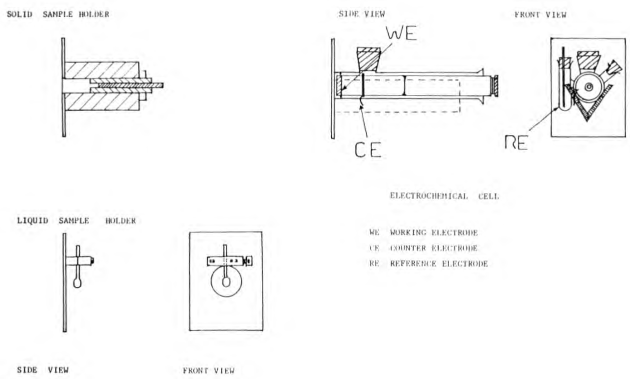


Figure 4b

Example of cells for F.T. Raman sprectroscopy. Solids are held in cylindrical holders, liquids in miniature glass flasks (vol ~ 80µL) and working electrochemical cells are shown above.

near infrared detectors are of only modest performance. Both Chase and Rabolt decided to exploit the considerable recent gains made in infrared interferometers, since they have largely replaced the conventional monochromator and reasoned that these devices would make near infrared Raman spectrometry feasible. Their assumptions were correct and Fourier Transform Raman Spectrometry was born.

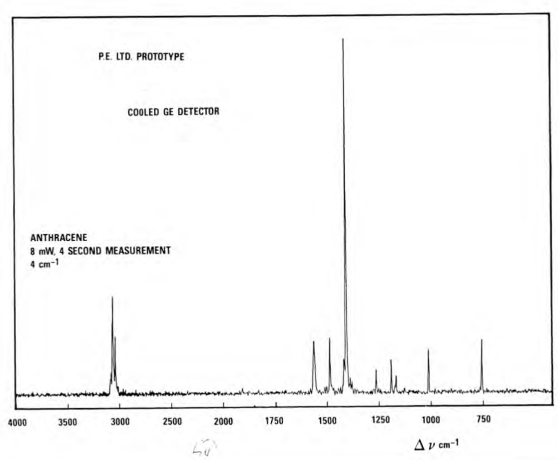
Later in 1986 we approached the Perkin Elmer Corp. at Beaconsfield near London, England and suggested that Chase and Rabolt's experiments might be possible using a low-cost analytical grade infrared interferometer modified to operate in the near infrared. A short collaboration was arranged and the outcome was very promising[5]. On the strength of this, Perkin Elmer placed equipment at Southamption in the Raman spectrometry group† including one of their 1700 series F.T. infrareds and a laser. Over the next 9 months, a fully operational instrument capable of running in the open laboratory and satisfying International codes of practice for the safe use of powerful invisible lasers was devised. Now in this fully developed form the machine requires no skill in operation and gives results at the rate of typically 10 specimen/hr. The machine was exhibited at Southampton to an International gathering on April 18th 1988 and then at the International Conference on Raman Spectrometry (ICORS 99) early in September 1988. Numerous industrial analysts were excited by its performance and versatility and 26 groups so far have been to Southamption to use it. Early progress in its use has been described[6].

The Southampton/Perkin Elmer Prototype Instrument

The instrument is based on a Perkin Elmer 1710 Interferometer. Mirror M_1 (see Figure 3) has been removed and a hole cut in the rear of the cover. The beam splitter BS, normally made of potassium bromide is replaced with one made of quartz and the infrared detector 'D' replaced by a near infrared sensitive device (Epittaxx In:Ga:As – running at room temp.). The instrument operates with its rear face towards the operator, the Raman experiment illuminating the Jacquinot (or entrance) stop of the interferometer 'J'. The sample is illuminated by a small Nd:YAG laser from Spectron Laser Systems Ltd. via a miniature prism P. Several high quality filters are used. F_1 ensures that the laser source is truly monochromatic. F_2, F_3 and F_4 are filters designed to block the scattered radiation at 1.064µ put pass the Raman scatter over the shift range $\Delta\nu$ 300 - 3500 cm^{-1}. Samples are held on simple vertical rails in front of the collection lens 'L' and the whole Raman sample area covered with a fully light-tight lid. This is interlocked with the laser so that opening the lid, blocks the laser. The sample

Figure 5a

Anthracene powder examined on the Perkin Elmer prototype spectrometer.



† The group has been supported by O.N.R. for several years and has pioneered a long list of applications of Raman spectroscopy to chemistry e.g. Surface Enhanced Raman Spectrometry[7] and the study of flames[8].

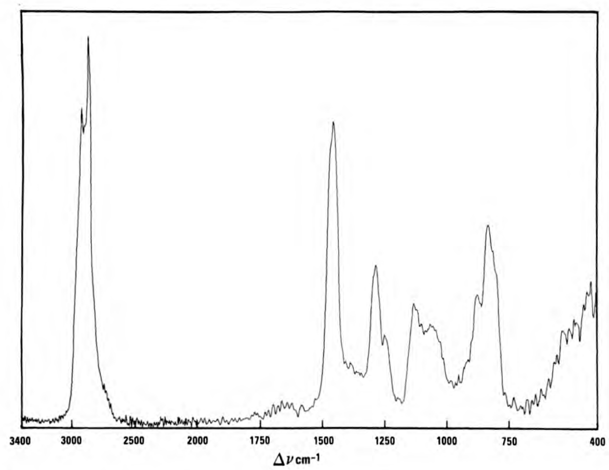


Figure 5b

Raman spectrum of hydraulic brake fluid.

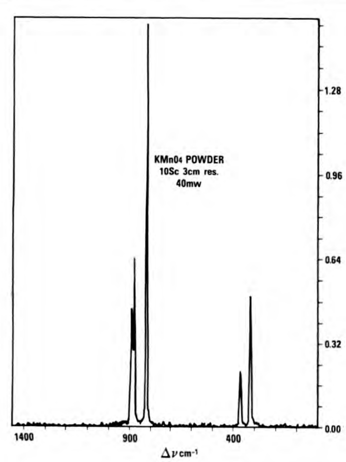
area is shown in details in Figure 4 with some examples of cells.

Spectra are recorded very rapidly, usually in a few minutes, whilst color and fluorescence are rarely overwhelming problems. As a result it is simple to record infrared and Raman spectra on a routine basis. To give some idea of the performance of the instrument we show spectra of anthracene recorded with only one scan of the Interferometer (Total time to display spectrum 4 secs.) in Figure 4 and an organic liquid (20 scans – time 30 sec.) in Figure 5.

The developed instrument has been described in detail.[9]

Figure 6

Potassium permanganate.



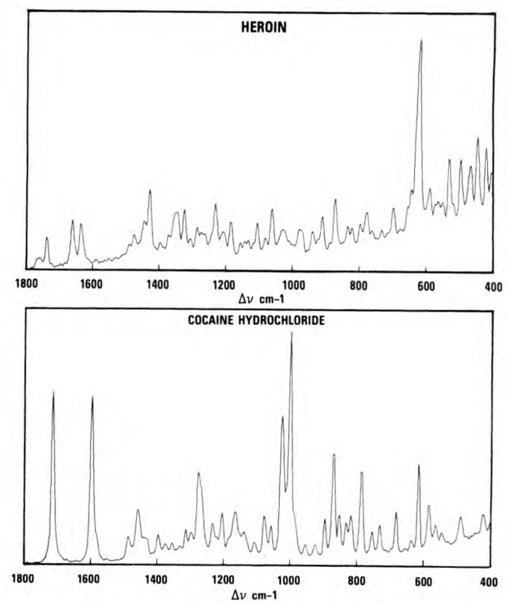


Figure 7a

F.T. Raman spectra of two narcotics.

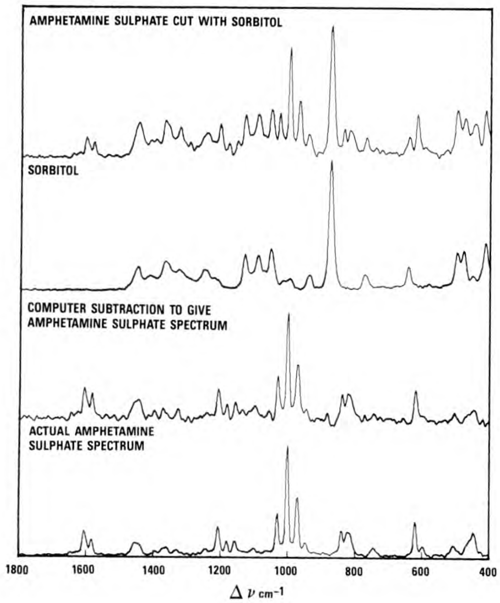
Some Applications

A considerable number of inorganic compounds are intensely colored and this has caused problems when attempting to record Raman spectra using conventional techniques. Some of these materials respond favorably to the near infrared. Examples of inorganic and organic colored materials are shown in Figure 6 both of which are almost impossible by conventional methods[10]. There are numerous examples of the analytical value of Raman measurements[11], but now such measurements are routinely available. The Southampton group is exploring these and examples are shown in Figures 7, 8 and 9. 'Street' samples of narcotics as small as a few mg in size can be identified using our instrument (Figure 7b). Officers from our local police force, the Hampshire County Constabulary were particularly enthusiastic about the trivially easy sampling method and the simplicity of operation of the instrument. Figure 8 shows spectra of some of the explosives so sadly used illegally. These samples were studied in special microcells. Note that samples as small as 6 μg are easily accessible. Those of us worried about the condition of our circulation might well study Figure 9. Measurements of the concentration of unsaturated species in foodstuffs are readily made.

Late in the 1960s, we showed that Raman spectroscopy was an excellent method for following reactions occurring on the surfaces of catalysts[12]. This vital area of industrial research urgently needs new techniques of study, but over the years Raman spectroscopy has failed to make any real contribution.

Figure 7b

Analysis of a street drug.



The problem is that catalysts fluoresce when exposed to reactants and the Raman spectra are obscured. We have re-appraised this area with our new instrument, with most encouraging results. In Figure 10 will be seen some examples

Figure 8

F.T. Raman spectra of explosives.

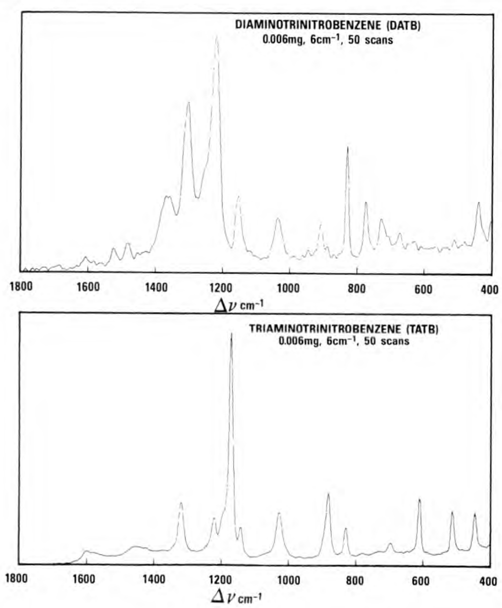
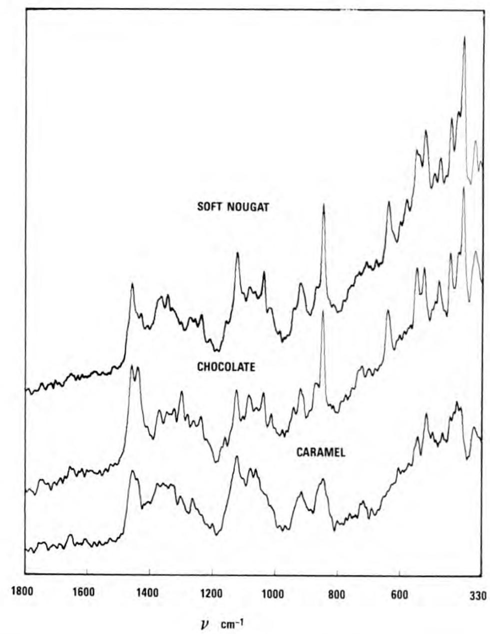


Figure 9

F.T. Raman spectra of a well known confectionary bar.



of spectra of organic molecules over commercial zeolite catalysts. It will be noticed that the method of the interaction between the adsorbate and the surface can be deduced from perturbations in the spectra of the adsorbate. These data can indicate to surface chemists, the nature of the active sites on the catalysts and hence in turn, the way they operate in the bulk synthesis of industrial chemicals.

If Raman spectra are recorded again and again on reacting materials they can sometimes yield data on the rates of reaction and hence, by deduction, the mechanism of reaction. Historically the method has been applied only rarely because of fluorescence but now exciting possibilities are opening up. In Figure 11 a unique Raman spectrum is shown – it is that of a brushed-on thin layer of a white paint bought from a supermarket. As the paint dries, the spectrum changes and the manufacturers are fascinated! They are able to follow point drying processes in situ and even to follow degradation reactions caused by sunlight, water and/or air.

Early in the 1970s, the Southampton group discovered Surface Enhanced Raman Spectroscopy (SERS)[7]. In an electrochemical cell, it was found that the molecules immediately in contact with a silver working electrode gave Raman spectra enormously enhanced in intensity compared with those in the bulk electrolyte. The method has been exploited because it provides a molecular level probe into the reactions occurring as a result of the applied voltage and it has been extended to

Figure 10a

F.T. Raman spectra of pyridene over a commercial H-Y zeolite catalyst.

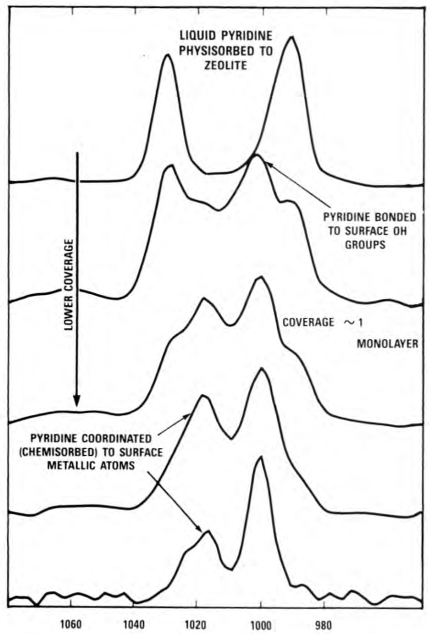
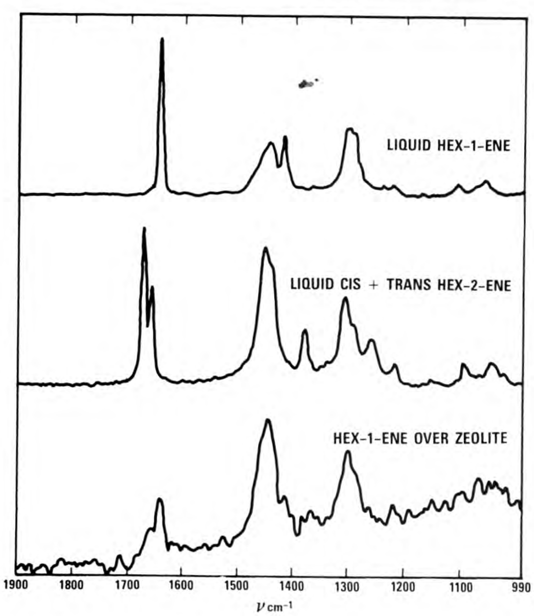


Figure 10b

Isomerization of hexene over H-Y zeolite at room temperature.

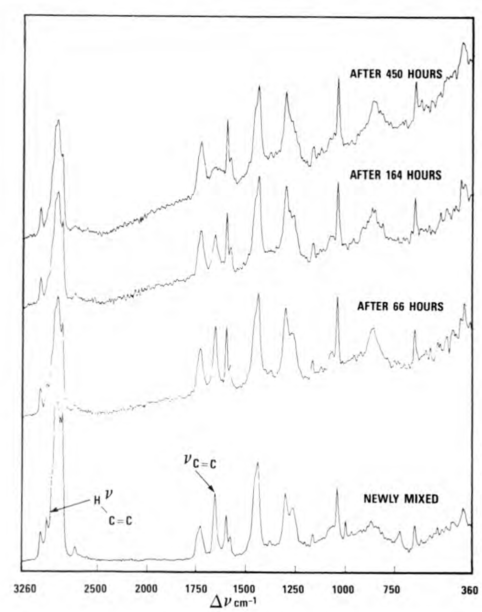


several other metals including copper and gold. This technique also operates well in the near infrared and one example is shown in Figure 12. The complete working electrochemical cell is fitted into the sample area of the machine and spectra accumulated at selected applied voltages. We have had success at copper, silver, gold and platinum surfaces [13,14] and plan to study several systems such as those involved in passivating metal surfaces, recovery of metals from their ores and electroplating.

Polymers and their properties are a special interest of ours, so in Figures 13 and 14 are shown examples of the spectra of rubbers and plastics. Many in the rubber industry would like to know more about the processes that occur as rubber is stretched. How can these processes be modified and better used to advantage? As you will see in Figure 13, the spectrum changes as the natural rubber is stretched. To unravel the data and interpret it is a daunting task we are undertaking at present. Many polymers show high levels of fluorescence (and vulcanized rubber is an excellent example!) but this problem is much reduced using F.T. Raman methods. In Figure 14 will be seen spectra of polyether ether ketone/glass fiber composites developed for the aircraft industry. Our interest here is in the morphology of the polymer matrix and its influence on strength and modulus. Numerous other polymer projects are seen to be yielding fascinating results e.g. the Isomerization that occurs during vulcanization, analysis of butadieneacrylonitrile synthetic rubbers, molecular order in polyether sulphones and many others. In this area, F. T. Raman spectroscopy is a definite step forward.

Figure 11

F.T. Raman spectra of a polymerizing alkyd varnish.



It would be dishonest to give the impression that everything works – it doesn't! When studying solutions in Raman spectroscopy the solvent of choice has always been water. The reason is that water has almost no spectrum of its own and is of course a superb solvent. As a result, numerous studies of dilute aqueous solutions abound in the literature. One area where aqueous solution chemistry is vital is in biochemistry but biochemicals usually fluoresce. Thus Raman work in this area has taken place[15] but made little impact. We have attempted at Southampton to explore the biochemical field with the new method but with little real success. Biochemicals when as solids or suspensions give good spectra but solutions do not, due to the fact that water absorbs in the near infrared. As a result, the Raman scatter is self absorbed by the specimen. Using D_2O does improve the situation but *dilute* solutions give very disappointing results.

In many cases, samples of a natural origin are damp or contain heavy contamination with water bearing moieties. These frequently give dreadful infrared spectra due to water absorption obscuring considerable ranges of the infrared and reducing the value of the fingerprint. In this area Raman can be of real value and an example is shown in Figure 15.

Figure 12

Pyridine absorbed on copper (E=0.9V/SCE). Oxidation-reduction cycle: potentials quoted versus SCE in V, time in s. Spectrum: 50 scans, resolution 3cm⁻¹.

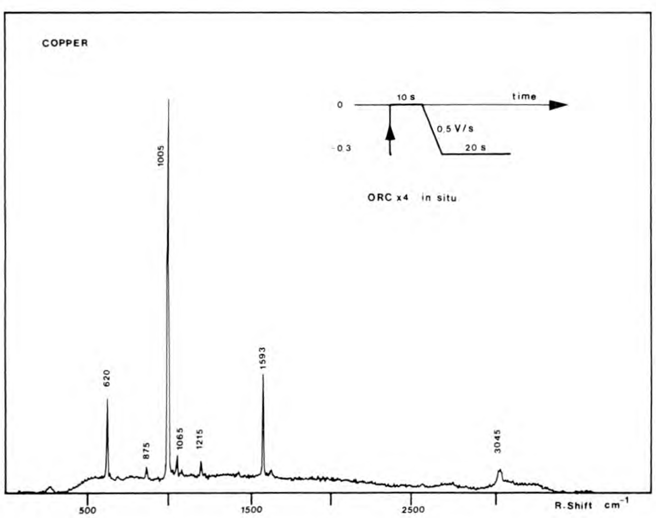
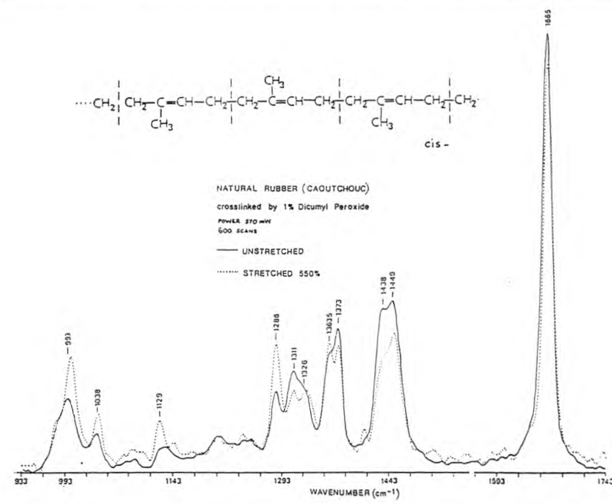


Figure 13

F.T. Raman spectra of stretched and relaxed natural rubber.



Conclusion

The impact of this new development in Raman spectroscopy has been particularly attractive to industrial analysts. Further, since only relatively minor alterations were required to the basic F.T.I.R. machine to make it operate as an F. T. Raman instrument it was immediately obvious that a high performance *combined* machine would be feasible. In June 1988, the Perkin Elmer Corp. based at Norwalk Conn. moved the exploitation of the project from its U.K. base to the United States and the Corporation launched a combined infrared/Raman machine based on the Southampton/Beaconsfield prototype at the Pitcon Instrument Exhibition in March 1989. Several other major manufacturers have products or prototypes including the Nicolet, Bomem and Spex companies in N. America and Bruker A.G. in German. Recently announcements have appeared that F. T. Raman can be carried out through a microscope[14] and remotely through optical fibers[15].

Raman will never be the same again – it has definitely moved out of the research environment into the routine laboratory.

Figure 14

Comparison of the F.T. Raman spectra of a homopolymer and a composite.

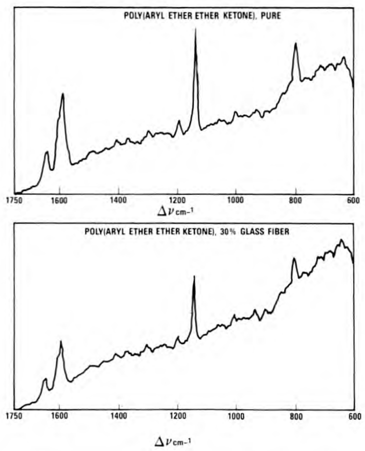
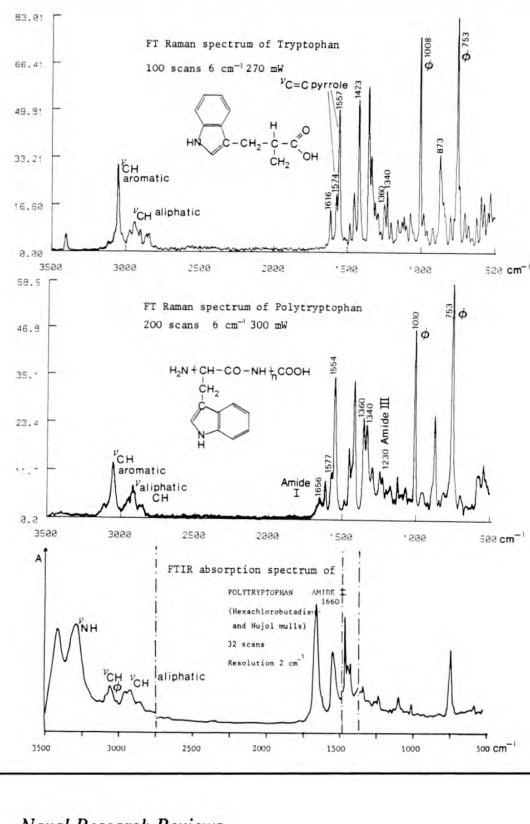


Figure 15

Raman spectra of a polypeptide.



Biography

Dr. Patrick Hendra is a Reader in the Department of Chemistry at the University of Southampton in the UK. He has researched in Raman spectroscopy since 1964 when he carried out pioneering experiments using laser sources with the late Professor Ellis Lippincott at the University of Maryland. He specializes in developing applications of the technique to chemistry in general and polymers and surfaces in particular.

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Synthetic Red Blood Cells

by Jeannine A. Majde, Office of Naval Research

Blood substitutes have long been sought to reduce the cost and improve the safety of replacing blood lost due to trauma or surgery. The armed forces are particularly concerned with finding an effective blood substitute to meet logistical demands and supply constraints during time of war. Fresh blood has a limited shelf-life and must be "matched" to the immunological characteristics of the recipient. Natural blood also carries whatever viruses were circulating in the donor, and while there are tests for some of the more important viruses (hepatitis B and human immunodeficiency virus-1 that causes AIDS), other blood-borne viruses are not yet detectable by known methods. The testing for viruses and elimination of infected blood substantially increases the cost and limits the supply of fresh blood. The advent of AIDS has greatly intensified the effort to develop a blood substitute free of viruses and capable of delivering oxygen in a physiologically compatible manner.

The red blood cell is one of the simplest cells in the body. It is comprised of a lipid membrane coated with certain sugar-containing molecules and is filled largely with a red protein, hemoglobin, the substance which handles the oxygen and carbon dioxide exchange so critical to maintaining living tissues. The relative simplicity of the structure and composition of the red blood cells lends itself to simulation with appropriate membrane lipids and hemoglobin or other oxygen carriers, as illustrated in Figure 1.

The idea of creating a synthetic red cell comprised of a semi-permeable membrane capsule incorporating blood hemoglobin was probably first articulated by T.M.S. Chang in his McGill University (Montreal, Canada) bachelor's thesis in 1957. Chang's efforts at creating the "microcapsule" for such an artificial cell was first published in 1964 and a wealth of concepts and methods for creating artificial cells of various types was provided in his monograph published in 1972. An artificial red cell concept using natural membrane lipids to encapsulate red cell lysates was described in 1980 and subsequently patented by L. Djordjevich and I. F. Miller. Refinements of this approach undertaken by C. A. Hunt at the University of California, San Francisco, were described in

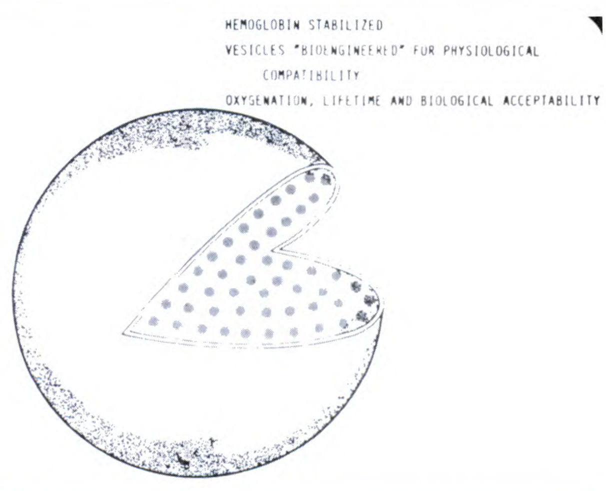

Figure 1

Schematic of liposome encapsulated hemoglobin; dots symbolize the hemoglobin molecules packed within a small lipid globule.

1985. However many of the practical problems associated with development of a biocompatible synthetic red cell were not conquered in these early efforts and have led to a program at the Naval Research Laboratory (NRL) in Washington, D.C., supported by the Office of Naval Research and the Office of Naval Technology, to make synthetic red cells a realistic approach to replacing natural blood.

The Navy's synthetic red cell concept is termed "liposome encapsulated hemoglobin" or LEH. LEH is composed of a single membrane layer composed of natural lipids (fatty materials) and purified hemoglobin. The hemoglobin can be combined with other substances that stabilize it or enhance its function. LEH is produced by techniques developed at the NRL by Drs. Bruce Gaber and Martha Farmer together with Dr. Richard Beissinger of the Illinois Institute of Technology, Chicago, such as it is composed of liposomes of a consistent small size, about 0.2 to 0.4 microns in diameter. A schematic of this procedure is illustrated in Figure 2. Liposomes of this size have the advantage that they exchange oxygen readily and will pass through small blood vessels that might trap much larger natural red cells (7 microns in diameter) and form clots. The relative sizes of LEH and a natural red cell can be seen in Figure 3. The physical properties of LEH also seem to contribute to its mechanical stability in the circulation, where blood components undergo dramatic pressure changes as they are pumped by the heart. Because the components are assembled after purification, it is relatively simple (compared to the situation with intact cells) to remove contaminating viruses prior to assembly and therefore assure safety. The methods developed at the NRL can be adapted to commercial scale-up with reasonable ease, and in fact, this is already underway.

The current LEH formulation has been demonstrated to have a half-life in the circulation of mice of approximately 20 hours, three times that of earlier formulations, and to sustain life in rats whose blood has been mostly replaced with LEH. Many animal studies remain to be done to determine the safety of LEH in both normal and traumatized animals, but these early results are very encouraging.

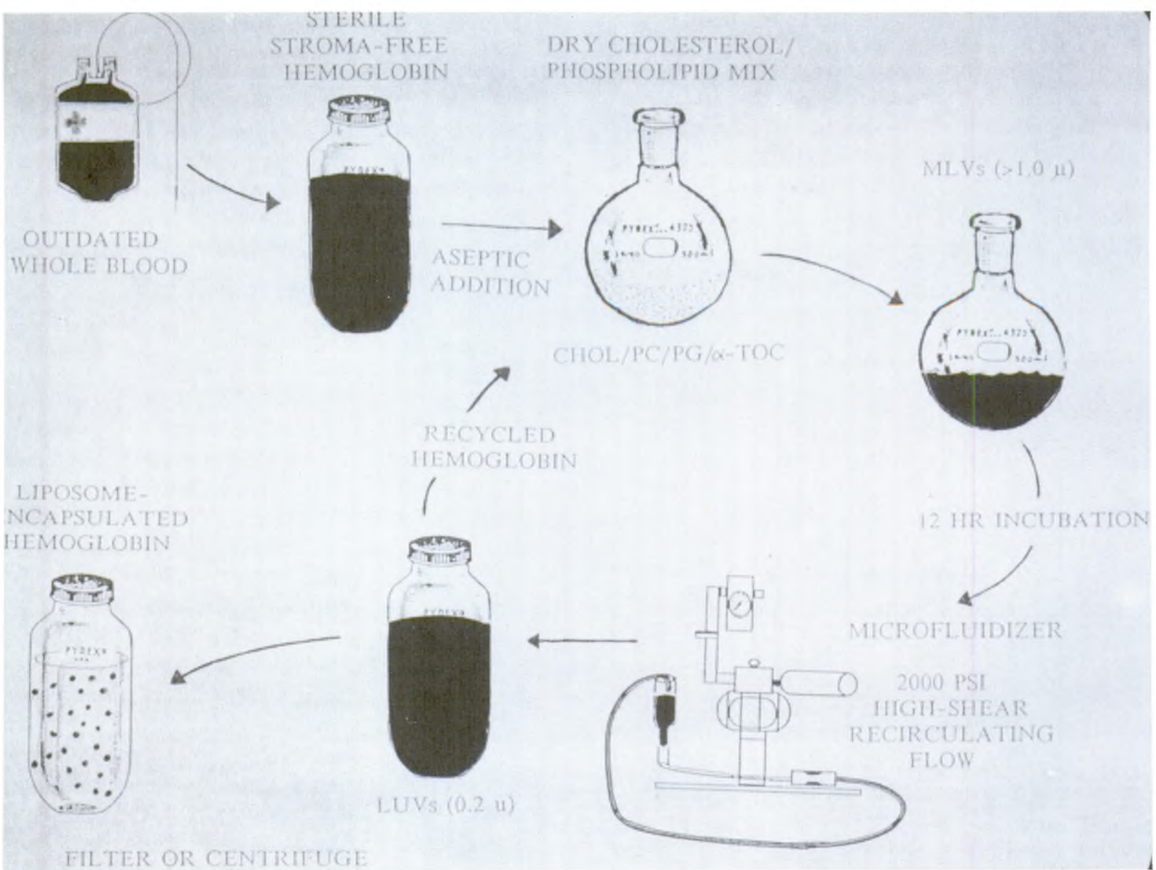

Figure 2

Schematic of LEH synthesis used by NRL.

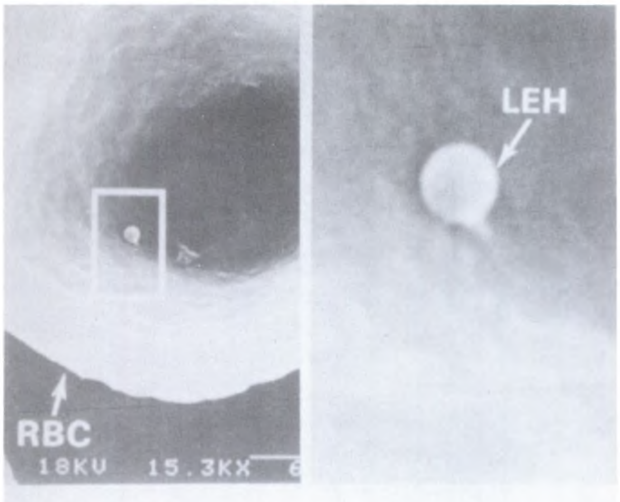

Figure 3

Scanning electron micrograph illustrating (left) the LEH (box) within the convexity of a natural red cell. A higher magnification of the LEH is shown on the right.

It is not possible at present to predict with certainty how the immune system will react to LEH. However, because the liposomes are free of known antigenic substances such as those found on natural cells, there is no reason in theory that LEH should be recognized as sufficiently foreign to induce an immune response. However, it might be possible to alter the surface of the liposomes such that they more closely resemble the surface of a natural red cell and "fool" the immune system more effectively. This strategy might have the distinct advantage of prolonging the circulation time of LEH, which are probably removed from the circulation by the recognition arm of the immune system termed the reticuloendothelial system. Because the external layer of sugars on a natural red cell is composed of the sugar sialic acid, a new Office of Naval Research program is exploring ways of adding this sugar to LEH in an economical fashion and determining if such a coating will prolong the lifespan of LEH.

Assuming LEH or a closely related synthetic red cell concept becomes a reality, the Navy and other potential users are still faced with shortage of hemoglobin to fill the liposomes. One solution under consideration is the use of bovine hemoglobin. However bovine hemoglobin has several structural differences that might cause immune reactions in humans, especially humans who have beef in their diet. Before bovine hemoglobin could be considered, extensive safety studies would be required.

Another approach under development is the production of human hemoglobin by recombinant DNA techniques. This approach shows great promise and a commercial product made by this means is currently being evaluated in the NRL program.

LEH has proven to date to be highly stable to storage at refrigerator temperatures and even at room temperature compared to natural blood cells. However, it would better meet the needs of its potential users, especially the military, if it could be stored as a dry powder without the need for freezing. Another program at the NRL, headed by Dr. Alan Rudolph, is investigating the possibility of freeze-drying LEH to achieve such long-term storage.

At present it is anticipated that LEH is unlikely to achieve the life-span of natural red cells in the circulation (about four months) and will serve primarily as a short-term blood substitute in mass casualty situations where fresh blood is not available. The LEH program is designed to supplement another long term Navy program directed at expanding the supply of fresh red blood cells of the so-called universal donor Type O class, the blood type that is immunologically appropriate for most people. This program, headed by Dr. Jack Goldstein of the New York Blood Center, New York, NY, converts the other major immunological types of blood cells, termed Type A and Type B, to Type O by treating such cells with common enzymes that selectively remove the Type A and Type B molecules. This approach is designed to double the amount of Type O blood available for transfusion. This Type O blood could then be stock-piled for many years using a freezing technique previously developed by the Navy. A probable side-benefit of the enzymatic treatment is that the processing of the blood that occurs with it will greatly reduce, if not eliminate, its content of contaminating viruses.

When an individual loses a lot of blood there are numerous physiological responses to that loss that complicate the physician's efforts to restore circulatory function. Unlike the situation with other liposome-encapsulated products that have been used with success in man, such as anti-cancer drugs, LEH must be well tolerated in very large volumes without further compromising the health of the recipient. It is anticipated that studies currently underway in the Navy program will resolve the potential utility of LEH for the treatment of massive blood loss within the next three years.

Biography

Dr. Majde is the Scientific Officer for Immunology, Cell Biology, and Medical Materials and Program Manager of Systems Biology at the Office of Naval Research. Her published papers and research have been primarily in the fields of virology and immunopharmacology. She conducts research on viral toxicology at the Uniformed Services University of the Health Sciences.

Research Notes

Dr. Saalfeld Receives Presidential Distinguished Award

The Director of the Office of Naval Research (ONR), Dr. Fred E. Saalfeld, received the rank of Distinguished Executive from President George Bush on September 14, at Constitution Hall in Washington, D.C. This distinguished award rated a $20,000 bonus.

Dr. Saalfeld was one of five Navy Department SES managers honored with distinguished rank. He was lauded for his performance as the senior line manager of the direction, management, and coordination of all programs under the Office of Naval Research and as the principal executive for matters related to the ONR corporate laboratories, branch offices, and detachments.

Dr. Fred Saalfeld is congradulated by President Bush on being awarded Distinguished Executive Rank.

(Photo credit: Carol T. Powers, The White House)

Dr. Saalfeld's government career began in 1963 at the Naval Research Laboratory (NRL) where he was first head of the Mass Spectrometry Section of the Chemistry Division, then head of the Division's Physical Chemistry Branch, and finally Superintendent of the Chemistry Division. While conducting research at the Naval Research Laboratory during the late 1970's, he conceived a life support system for submarines which is used in all Navy submarines. That project, he says, was one of his most satisfying career achievements.

In 1979 he became Chief Scientist and Scientific Director of the ONR Branch Office, London, in 1982 he took over as Director of ONR's Contract Research Program, and in 1987 he became Director of ONR.

His many accomplishments in ONR have significantly enhanced the nation's ability to face future challenges through such breakthroughs as free electron lasers, fiber optics, biotechnology for a new universal blood, and Argo-Jason (the deep submergence system used to discover the Titanic and Bismarck).

Since becoming Director of ONR, Dr. Saalfeld's leadership and management have achieved notable success in focusing Navy research in areas where science can best serve our national defense requirements.

He has consolidated the three ONR environmental laboratories into the Naval Oceanographic and Atmospheric Research Laboratory (NOAPL) at the Stennis Space Center, Mississippi. This new corporate lab will be a major step forward in research in the environmental sciences and is ultimately expected to grow into a world-class research center on a par with NRL.

He established ONR's Naval Ocean Modeling and Prediction program to coordinate ocean modelling toward development of a synoptic ocean prediction capability for the fleet in the 1990's.

He instituted the broad-based Senior Scientific ONR Council (SSOC) to provide a high level forum for interaction among Navy research senior scientists and managers, both from ONR headquarters and its corporate labs.

Under his guidance, ONR significantly improved the obligation and expenditure rates of basic research funds, exceeding NAVCOMPT goals in 1989 for the first time.

Throughout his 26-year civil service career, Dr. Saalfeld has accrued numerous awards and honors. Among them are the Robert Conrad Award (1989), Navy Superior Civilian Service Award (1987), and Meritorious Civilian Award (1986), SES Meritorious Rank (1986), SES bonuses (1980, 1982, 1985, 1987, 1988), and the Navy Superior Merit Award (1978).

With a staff of nearly 400 scientific officers and support personnel, the director of the Navy's basic research effort says his goal is to retain and improve upon ONR's "greatness and its high quality reputation in science."

Three OCNR Scientists Receive Presidential Meritorious Rank

Dr. Albert Faulstitch, Jr., (left), Dr. Bruce B. Robinson (standing), and Dr. Bobby R. Junker (right) received recently the rank of Meritorious Executive from President Bush during ceremonies at Constitution Hall in Washington, D.C. Each meritorious award rated a $10,000 bonus.

Dr. Robinson, Associate Director of the Office of Naval Research and Director of the ONR Research Programs Department was lauded for his "very effective" performance as the manager of a $350 million research program which has significant impact on Navy requirements and on the national technology base. Through his leadership, the Research Program Department realized its most productive year to date, showing increases in publications, graduate students supported and research transitions. Dr. Robinson implemented an in-depth research program review and planning process using panels of nationally-recognized scientists and potential Navy users.

Dr. Junker, Director of Mathematics and Physical Sciences at ONR, was honored for consistently seeking emerging research opportunities which offer significant potential for naval systems. For example, he spearheaded research related to the measurement of stellar objects important to navigation which have already led to an order of magnitude increase in star positions and should, in the near future, provide several orders of magnitude improvement in the resolution of celestial images. Dr. Junker organized a significant cost-saving, automated research and contract management system for execution and tracking the ONR research program.

Dr. Albert J. Faulstitch, Jr., Director of Antisubmarine Warfare and Undersea Technology at the Office of Naval Technology, was noted for improving the defense posture of the United States by focusing the efforts of the Navy's ASW technology community onto critical research and development programs. Dr. Faulstitch has been the principal architect in defining focal concepts for ASW systems for the year 2015. These concepts are serving as drivers and integrators for the technology programs currently being launched.

Calciphor

Dr. Jeannine A. Majde, ONR

The following outlines the known properties of Calciphor, a family of drugs under investigation by the Office of Naval Research (ONR). This drug family has demonstrated a number of unique characteristics *in vitro* and *in vivo* that suggest it may constitute an effective therapeutic agent for ischemic injury, reperfusion injury and other forms of cellular injury.

Calciphor structurally is an oligomer (dimer, trimer, tetramer) of 16, 16'-dimethyl-15-dehydro-prostaglandin B_1. The Navy's interest in Calciphor is based on observations with a crude mixture of 15-dehydro-prostaglandin B_1 oligomers, termed PGBx, originally prepared by Dr. B.D. Polis of the Naval Air Development Center. Polis observed that PGBx could protect the synthesis of ATP by mitochondria subjected to anoxia. In subsequent *in vivo* studies, PGBx was shown to improve survival of monkeys subjected to myocardial ischemia and rabbits and gerbils following cerebral ischemia. It also protected mice subjected to hypoxia, prevented development of stress ulcers in rats, and improve motor function in rabbits after spinal cord ischemia. The original observation of the effect of PGBx on mitochondria was confirmed by Dr. T. M. Devlin of Hahnemann University, who continues to investigate the mechanism of action of PGBx.

Because PGBx is a crude and complex mixture, its synthesis and biological effects are erratic. A new chapter in the ONR story began in 1983 when Dr. G. L. Nelson of St. Joseph's University synthesized and separated defined structural dimers, trimers and tetramers of 15-dehydro-prostaglandin B_1 and also 16, 16'-dimethyl-15-dehydro-prostaglandin B_1, now termed Calciphor. Calciphor oligomers all demonstrate comparable biological activity in Dr. Devlin's *in vitro* mitochondrial assay whereas the monomers are inactive; the dimer and trimer of Calciphor have been tested and found comparable to one another in one well-characterized *in vivo* model (gerbil stroke); the monomer is inactive. The simpler structure of the dimer makes it the drug of choice for further development, but the data to be presented and discussed here include *in vivo* studies with the trimeric form as well as the dimer.

The original name selected for the defined oligomers of 16, 16'-dimethyl-15-dehydro-prostaglandin B_1 was oligoprostaglandin B or oligoPGB, and several publications have come out under that nomenclature. We have recently adopted the name Calciphor (based on a proposed mode of action described below) for these defined synthetic oligomers; the reader should be aware that the attached data and publications cited below do not employ the name Calciphor but instead refer to either the dimeric or trimeric forms ofoligo-PGB.

Our current concept of the mechanism of action of Calciphor is that it controls intracellular Ca^{2+}; the drug can transport Ca^{2+} out of mitochondria as well as out of the whole cell (Uribe, *et al*, Biochem, Biophys. Res. Comm. *143*:1024, 1987) in exchange for K+ and/or Na+ ion (Uribe, *et al.*, Biochem, Biophys, Acta 924:87,1987). The accumulation of Ca^{2+} ion in cellular compartments, especially mitochondria, is known to be one of the lethal events occurring during ischemia and reperfusion injury. (Ca^{2+} is present in the extracellular fluid at concentration 4 orders of magnitude higher than its concentration in the intracellular fluid; thus Ca^{2+} accumulates passively in injured cells whenever membrane integrity or energy reserves fail.) Studies to date suggest that Calciphor can reverse the lethal accumulation of Ca^{2+} ion and assist the injured cell in restoring its capacity to generate ATP and other essential metabolites.

In vitro studies have demonstrated that Calciphor also inhibits selected calcium-dependent enzyme, including phospholipase. Calcium dependent phospholipase (particularly phospholipase A_2) are thought to be involved in membrane degradation and accumulation of eicosenoids during ischemia; inhibition of this cascade may be another site of Calciphor's action. This same property induced the ONR to investigate whether Calciphor has anti-inflammatory action; it was found to be anti-inflammatory in a standard mouse model. The relative roles of iontophoresis vs. enzyme inhibition (or associated anti-inflammatory activity) in the protective effect of Calciphor in ischemia are not yet known.

A substantial protective effect of Calciphor has been demonstrated in the gerbil cerebral ischemia model. Data acquired by Dr. D. von Lubitz this model are attached. The most dramatic protection is seen when two injections are administered about 24 hrs. apart. This dose regime, however, is in no respect definitive, but simply the best of those few that have been tested. (A similar model was previously used to test PGBx with encouraging results; but as in other studies with PGBx, the results were erratic. This has not been a problem with Calciphor.)

Another model in which consistent positive results with Calciphor have been seen is renal ischemia in the rat, a model developed by Dr. L. Mela-Riker of the Oregon Health Science Center. An abstract of her preliminary results and some data are attached. In this model, which employs unilateral ligation, it has not been possible to demonstrate Physiological dysfunction in the controls. It is expected that the mitochondrial preservation she sees will be expressed as improved functioning of the injured kidney.

It should be noted that in all models tested to date the dose range was approximately 1-10 mg/kg administered i.p. either one or two times AFTER reperfusion was initiated. Calciphor has not demonstrated prophylactic activity in any models tested. This observation is compatible with the proposed mechanism(s) of action. It should also be noted that because Calciphor is a lipid, it is able to diffuse rapidly and penetrate the blood-brain barrier, as evidenced by its protective effect in cerebral ischemia following parenteral injection. The effective dose is well below that which produces acute toxicity with PGBx in mice.

Calciphor represents a novel approach to treating cellular injury. It is the only available drug that is capable of working *within* the injured cell to protect essential metabolic functions. It appears to readily diffuse throughout the body, including the brain. The *in vivo* studies performed to date in ischemia models with Calciphor are extremely encouraging. Numerous applications of such a drug can be envisioned, not only in the obvious conditions of myocardial infarcts, stroke and hemorrhage, but in militarily important conditions such as non-freezing cold injury, decompression sickness, etc., where ischemia plays an important role. Calciphor, combined with extra-cellular protectants (e.g., clot-dissolving enzymes, calcium channel blockers, adenosine receptor agonists, free-radical scavengers, etc.), is a rational therapeutic for reperfusion injury. *In vitro* applications, such as maintaining stored blood components and perfused organs for transplantation, have not yet been explored. The central role that calcium ion plays in cellular injury and function will undoubtedly lead to medical applications of Calciphor not yet conceived.

Technique Gives Inside Look At Cyclones/Hurricanes

A team of scientists at the Naval Research Laboratory (NRL), reports that the joint Navy/Air Force Sensor known as the Special Sensor Microwave/Imager (SSM/I), has demonstrated the capability of "looking beneath dense clouds to accurately position and trace hurricanes and typhoons, to determine their water content, and to map the directions, as well as the speeds, of the winds.

The SSM/I, built by the Hughes Aircraft Company, measures critical atmospheric, oceanographic, and land parameters on a global scale. These parameters include the detection and measurement of rain storms, ocean surface wind speed, the mapping of sea-ice concentration and ice/water boundaries, and land surface moisture, land type and temperature.

Informational data on storms provided by the SSM/I are aiding the Navy, the Department of Defense and the nation at large by contributing advanced hurricane, cyclone, and other storm warnings to aircraft, naval and commercial shipping, pleasure and fishing boats, and shore inhabitants. The obtained information is made available to weather personnel and contributes to the national weather forecasting systems.

The NRL team, charged with managing and coordinating the multi-agency effort for calibration and validation of the SSM/I, says the contributions of the space sensor are becoming even more important because of the curtailment of aircraft reconnaissance flights into Pacific typhoons. For reconnaissance flights into Atlantic hurricanes, the SSM/I can provide aircraft with accurate initial bearings and other data, which lead to more accurate positions and warning lines and better forecasts.

Team members, Mr. Glenn Sandlin, an NRL physicist, and his associate, Mr. David Spangler, an engineer with the Bendix Field Engineering Corporation, who are spearheading the research, report the SSM/I has monitored the development and course of 75 percent of the tropical storms and cyclones that have occurred since the imager's launch aborad the Defense Meteorological Satellite (DMSP) in June 1987. Mr. Sandlin performs research and development of new SSM/I techniques and algorithms while NRL's Dr. James P. Holliger is the principal investigator in the SSM/I project research.

Sandlin reports that the SSM/I's global, day/night, all weather surveillance capability is providing valuable, cost-effective data for precisely locating storms and for determining their physical characteristics. Because the microwave radiation from storms can penetrate the dense overlying cirrus clouds with very little attenuation, it reveals physical details through the use of the SSM/I that are not always depicted by visible and infrared images, including the eye of the vortex, the structure of deeply convective regions, and information on the wind in the gale envelopes. A new SSM/I algorithm combines the windspeed information with routinely available atmospheric pressure data to compute the directions of the wind. These SSM/I vectors are especially useful, not only in cloud-free regions, but for scenes that are under cover of darkness or cirrus clouds where low level (cumulus) cloud movements are not visible from the GOES satellites.

The DMSP-SSM/I completes 14.1 revolutions per day along a sun-synchronous track above the solar terminator, included at 98.8 degrees to the equator in an 833 kilometer orbital altitude. Sandlin says the SSM/I, with an observational swath width of 1,400 km, has an 89-percent probability of viewing a storm in the tropics at least once a day. A second SSM/I, scheduled for launch early next year, will increase the probability to 99-percent. Images of the scene are produced by scans with vertically (V) and horizontally (H) polarized microwave radiometers tuned to frequencies, 19.3, 22.2, (V only); 37.0 and 85.5 gigahertz.

Sandlin concludes that the SSM/I imagery of storms can be an advantage in precisely locating the eye and in delineating near-gale and gale force winds. Along with all of the validated SSM/I retrievals, the images can be obtained day or night, under any kind of cloud cover. The SSM/I products provide global, consistent, and cost-effective meteorological information as accurate as those of buoys and ships. Sandlin is recommending that studies of the SSM/I be continued so that further improvements on its operational capabilities can be made.

LIPS Satellite Used In Solar Cell Study

A scientist at the Naval Research Laboratory (NRL) reports the Laboratory's Living Plume Shield (LIPS) III research satellite, launched in the spring of 1987 and carrying a large number of solar cell experiments, is providing scientists with invaluable scientific data on the physics of solar cells in a space environment.

Mr. James Severns, chief scientist of LIPS III, says the spacecraft has 140 separate experiments on silicon, gallium-arsenide and indium-phosphide solar cells and cover-glass adhesives. The solar cells were supplied by 18 activities, including universities, industrial manufacturers, NRL, and other agencies.

The LIPS spacecraft, a converted spacecraft plume shield, is providing scientists with real-time information that will be used in improving solar cells of the future.

Mr. Severns notes that data from the NRL satellite was highlighted recently in papers presented at the 24th Intersociety Energy Conversion Engineering Conference held at Crystal City, in Arlington, Virginia.

At the conference LIPS experimenters discussed the measured interaction of the space environment with advanced experimental solar cells, such as vertical junction silicon cells, and gallium-arsenide cells with high-temperature welded contacts.

Mr. Mark Thompson, of the Boeing Company, reported on what is known as the "light funnel" concentrator/solar cell combination, a Boeing invention. The inclusion of the solar cells illuminated by optical concentrators aboard the satellite is "particularly interesting," since LIPS III provides the first space test of such combinations, Mr. Severns comments.

Also, included aboard the LIPS III research satellite is the minicassegrainian solar-cell system featuring mirrors to focus sunlight onto a gallium-arsenide solar cell that was developed by TRW, and the SLATS system from General Dynamics using single-axis parabolic trough concentrators, that resemble venetian blinds. The LIPS III experiments, including the concentrators, are performing well and providing useful data after two years in orbit.

LIPS III was launched in the spring of 1987 into a 1100-kilometer, 60-degree inclination orbit. The spacecraft was designed as a test bed for new photovoltaic power devices under the direction of Mr. James Winkler of NRL's Space Systems Development Department.

The use of the living plume shield-type devices used to protect satellites when they are launched is an idea of Mr. Peter Wilhelm, Director for NRL's Naval Center for Space Technology. From conception to launch, the LIPS III spacecraft took less than one year to produce.

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