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Sandia Laboratories Technical Capabilities

Testing

MASTER

Sandia Laboratories

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MASTER

SANDIA LABORATORIES TECHNICAL CAPABILITIES

TESTING

ABSTRACT

This report characterizes the testing capabilities at Sandia Laboratories. Selected applications of these capabilities are presented to illustrate the extent to which they can be applied in research and development programs.

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FOREWORD

Sandia Laboratories, a multiprogram laboratory of the Energy Research and Development Administration (ERDA), is located in Albuquerque, New Mexico, and Livermore, California, with a remote testing facility at Tonopah, Nevada. In fulfilling its responsibilities to ERDA in the fields of national security, energy, and other programs, Sandia has acquired extensive capabilities in research, development, testing, and evaluation, and has made numerous contributions in scientific and engineering fields. These technical capabilities are integrated by management for the definition and solution of scientific and engineering problems.

A series of reports has been written describing these capabilities and showing typical applications. The reader will find the capabilities summarized in a separate paper, or may choose any of the 17 separate reports, or, if he wishes a compendium, can find all the reports and the summary compiled in a single publication. Identifying numbers for the entire series are given below.

C. Donald Lundergan, Technical Editor
P. L. Mead, Publication Editor

TECHNICAL CAPABILITIES OF SANDIA LABORATORIES

Summary
(SAND74-0091)

Aerosciences	SAND74-0075	Instrumentation and Data Systems	SAND74-0083
Applied Mathematics	SAND74-0079	Materials and Processes	SAND74-0073A
Biosciences	SAND74-0076	Measurement Standards	SAND74-0077
Computation Systems	SAND74-0080	Physical Sciences	SAND74-0074
Design Definition and Fabrication	SAND74-0084	Safety and Reliability Assurance	SAND74-0090
Earth Sciences	SAND74-0085	Systems Analysis	SAND74-0089
Electronics	SAND74-0086	Testing	SAND74-0088
Engineering Analysis	SAND74-0087	Auxiliary Capabilities: Environmental Health, Information Sciences	SAND74-0082
Explosives, Electrochemistry, and Electromechanisms	SAND74-0081		

Compilation of
Sandia Laboratories Technical Capabilities
(SAND74-0092)

TESTING*

Extensive test facilities have been developed to simulate mechanical, thermal, hydrodynamic, electromagnetic, and radiation environments. Research, development, and evaluation testing facilities are used to explore new concepts and to evaluate proposed and existing designs. Facilities include shock, vibration, surface impulse, blast loads, thermal, aerodynamic, underwater, and electromagnetic for the simulation of environments. Radiation sources have been developed to provide a simulation of nuclear effects tests. Pulse reactors provide a mixed neutron-gamma exposure. Steady-state neutron and gamma irradiation are provided by a neutron generator and ^{60}Co and Cs radiation sources. Bremsstrahlung x-ray and electron beam exposures are performed using the pulse accelerators. Test facilities used primarily in support of the Laboratories' exploratory research and development effort are wind tunnels, plasma jets, shock tubes, and flight simulators to support aerodynamic testing; and high-velocity gas guns, and explosively and magnetically driven flyer plate facilities to support the materials characterization effort in solid dynamics and structural studies. Materials, structures, components, and entire integrated systems are evaluated using a wide variety of nondestructive testing techniques such as flash x-ray, acoustic emission, laser holography, ultrasonics, and x-ray and neutron radiography. Field-testing capabilities include mobile instrumentation vans that can be deployed worldwide, a rocket-launching facility at Kauai in Hawaii, an isolated area at Nevada Test Site for underground nuclear testing, and the Tonopah Test Range for a wide variety of aerodynamic testing.

In addition to providing test facilities for engineering programs, the responsibility of the testing function includes anticipating future test requirements and integrating test plans with project, research, and advanced development organizations for the design of meaningful test programs.

Only test facilities that are common to several programs are discussed in this section. Facilities to support special objectives or single programs are omitted here, but are described in other sections of the Technical Capabilities report.

Testing Technical Staff and
Investment in Equipment

	Professional Staff	Investment in Equipment ($1000)
Environmental Simulation	72	37,210
Mechanical Loading		
Radiation Loading		
Research, Development, and Evaluation	55	8,275
Aero Testing		
Material Response		
Nondestructive Testing		
Field Testing	61	30,500
Tonopah Test Range		
Nevada Test Site		
Kauai Test Facility		
Mobile Testing		

*Compiled April 1975

ENVIRONMENTAL SIMULATION

The purpose of this function is to furnish research, design, and development engineers with test results that encompass anticipated handling and use environments. To support the requirement for a wide variety of stimuli, test facilities have been established that simulate various environments including several types of mechanical loading (static, shock or impact acceleration, vibration, and surface impulse) and radiation loadings (thermal, electromagnetic, neutron, x-rays, electron, and gamma rays).[†]

Mechanical Loading

Research and development test facilities are used to simulate several types of mechanical loading. The dynamic simulation testing capability consists of a variety of shock-testing machines, including electrodynamic and hydraulic vibration actuators. These machines are computer-controlled for sinusoidal and random vibration, and shock-controlled pulses. Other mechanical loading facilities provide for earth-penetration testing, surface-impulse simulation, acceleration time signatures, blast loading, and explosives testing. Combined environments can also be simulated, such as temperature plus vibration or impact, or vibration during acceleration. Underwater facilities provide the capability for water-entry testing as well as high-speed hydrodynamic investigations.

New test techniques, test control methods, data acquisition and analysis systems, and instrumentation are continuously being developed to improve simulation capabilities. The facilities are adaptable to particular test requirements.

Static Mechanical Loads

Static loading tests are performed to determine the ability of structures to resist loadings expected in use and to satisfy the needs of fundamental research with respect to material properties. Loadings can be induced from external point sources, from area loads as in hydrostatic pressurization, and from inertial body forces such as sustained acceleration. Facilities can accomodate a broad spectrum of loading conditions and test item sizes. Some combinations of external point loading and body force loading are possible, and on some equipment, tests can be conducted at temperatures other than ambient. (Item 1)*

[†] Test facilities are presented only under the generic headings indicating their use. Detailed descriptions of the simulation facilities mentioned in this section are available in the Sandia publication "Environmental Test Facilities," June 1972.

Current Facilities

- Centrifuges
- Tension-compression testing machines
- Load frames
- Hydrostatic pressure chambers
- Creep high temperature testers

Shock or Impact Loading

Shock-controlled pulse or impact testing is used to evaluate the structural and functional integrity of components, subsystems, and entire systems to a prescribed transient response. Transient response techniques are also used in combination with analytical and numerical techniques to determine mechanical properties of materials. Techniques and facilities have been developed to provide a wide range of shock-controlled pulse shapes. (Items 2-9)

* See Highlights below.

Current Facilities

- Actuators
- Drop towers
- Shock machine
- Flyer plates
- Air guns
- Centrifuges
- Rockets
- Rocket sleds
- Aerial cable
- Blast tubes
- Earth penetrators

Surface Impulse Loading

Facilities have been developed for loading material samples, structural shapes, and full-scale systems with short duration (1 to 10 μs) pressure pulses. Stress waves generated by an impulse in combination with structural response may lead to major structural and material damage. Explosives and explosively or magnetically driven flyer plates have been developed to simulate radiation-induced blowoff impulse and to determine stress-strain relations for structural materials under high strain rates. Electron-beam irradiation is also used to simulate transient surface-loading conditions on small material samples. (Items 10-11)

Current Facilities

- Light-initiated explosives
- Mesh-initiated explosives
- Propagating explosives
- Gas driven flyer plates
- Explosively driven flyer plates
- Magnetically driven flyer plates
- Electroexplosives
- Electron beams

Random and Sinusoidal Vibration

Vibration tests are performed on components, subsystems, and entire systems either to determine the response of the configuration to a specified level of excitation, or to define excitation levels and spectra that induce failure. Vibration testing is also used to determine the response and resonance frequencies of configurations to a low level specified excitation spectrum for analytical modeling purposes.

Vibration facilities are composed of electrodynamic drivers supplied by electronic amplifiers under programmed servo control. Options include swept sinusoidal, random, swept sinusoidal on random background, and swept random on random background.

Control capability consists of analog techniques for sinusoidal excitation, digital methods for random excitation, and analytical techniques for transfer function determination. Analyses are generated in quasi-real time with plots of power spectral density, shock spectra, transmissibility, transfer function, and Fourier spectra versus frequency, as well as printouts of eigenvalues and spatial eigenvectors. (Item 12)

Current Facilities

- Electrodynamic shaker drivers
- Hydraulic actuators
- Spectral density analyzer/equalizer

Acceleration/Time Loading

In the design and qualification of some components and subsystems, a major requirement is that they withstand acceleration loading for a specified time. Acceleration-time profile testing is used to properly exercise inertial devices and to determine their ability to measure acceleration, velocity, or distance. Missile launch, in-flight reentry conditions, staging, parachute deployment, and other such conditions can be duplicated or simulated. Emphasis is placed on reentry simulation for the test of inertial devices, but other noninertial items are tested, especially where systems interact with inertial devices. A rocket sled track, available for testing large items, can be used with advantage to simulate effects of missile launch and staging. (Items 13,14)

Current Facilities

- Centrifuges
- Rockets
- Rocket sleds

Explosives Firing

Facilities with explosive load limits to several thousand kilograms are in operation. Instrumentation available includes oscilloscopes, tape and disk recorders, high-speed framing and streak cameras, flash x ray, and a time-resolved spectrograph.

ENVIRONMENTAL SIMULATION

Current Activities

- Tests on explosive systems
  - Shock
  - Vibration
  - Temperature
  - Humidity
  - Pressure
  - High-speed spin
- Tests utilizing explosive systems
  - Flyer plates
  - Containment
  - Pulse power sources
  - Component qualification
  - Overpressure
  - Vulnerability
  - Electrically initiated plane wave generators
  - Cratering
  - Response of materials to shock loading

Underwater Testing

Technologies and facilities have been developed to study phenomena related to high-velocity hydrodynamics and pressure effects. Full-scale and model entry studies are conducted in water tunnels. The rocket sled track is used for larger or higher velocity full-scale water entry studies. (Item 15)

Current Facilities

- Water impact
- Water tunnels
- Rocket sled track

• • • • • • *HIGHLIGHTS* • • • • • •

Item 1. *7.6-Metre-Radius Centrifuge*

The distribution of internal loads in a complex structure subjected to combined axial, lateral, and bending loads can be determined using the centrifuge to apply a steady-state acceleration field in conjunction with hydraulic jacks used to apply local bending moments. This centrifuge has a radius of 7.6 metres and can accelerate an 8-ton specimen to 100 x earth gravity (Figure 1). Specimens of less weight can be accelerated to a maximum of 250 x gravity within the dynamic load rating of 1.6×10^6 gravity-pounds. Specimens being tested can be concurrently subjected to temperatures from −65 to 350°F and vibration frequencies from 10 to 3000 Hz.

Item 2. *Earth Impact Testing*

The effects of earth impact on air-dropped munitions can be simulated using a rocket pull-down technique developed at the aerial cable facility. Before development of this technique such detailed evaluations of full-scale systems could only be made statically with pre-positioned munitions, since airdrop accuracy is not sufficient to reliably position munitions in an instrumented arena.

A 1200-kg fuel-air explosive was tested using this technique. The munition was raised by a hoisting line to a release point on the overhead cable. Two towing lines ran from the munition to the impact point in the center of the instrumentation arena. Guide tubes buried under the target area redirected the towing lines to a rocket sled at the end of a track as shown in Figure 2. The release point on the overhead cable was selected to provide the desired impact angle of 70 degrees. Impact velocity was 250 m/s. Ground and overhead cameras recorded aerosol growth rate until detonation by pre-positioned ground initiators. Yield was determined from pressure transducers in the target arena.

Figure 1. 7.6-metre-radius centrifuge

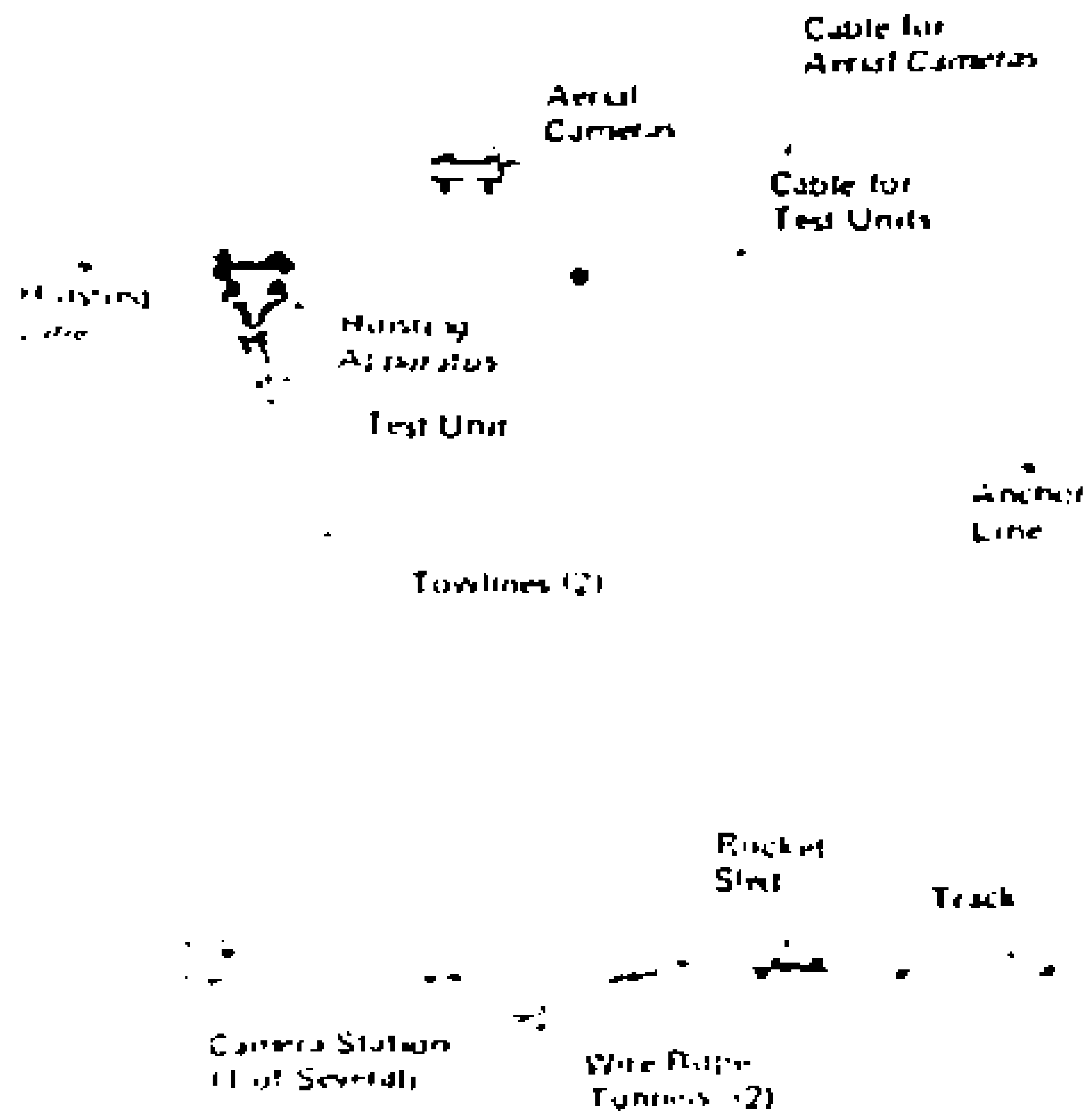


Figure 2   Aerial cable facility

This facility is used to impact masses of up to 10,000 kg into almost any target material, earth, water, concrete, steel, even trees. Impact velocities of 300 m/s have been achieved with lesser masses. Facility capability is limited to combinations of mass and velocity that have a maximum kinetic energy of 40 MJ.

Item 3.   *Pneumatic Actuator Facility*

Mechanical shock tests were conducted using the pneumatic actuator facility (Figure 3) to produce a programmed acceleration loading profile that simulated the environment resulting from blast loading. The actuator was used in the thrust column driven sled mode for this test series. This mode consists of an air-driven actuator applying a force through a piston-driven thrust column to a sled mounted between two rails 610 mm apart. The maximum force that can be applied to the sled is 2.45 MN with a maximum stroke of 0.9 metre. Velocities available range from 80 m/s with a 115-kg sled to 40 m/s with a 900-kg sled. Accelerations up to 2000 x gravity may be obtained using this sled mode.

To achieve higher accelerations or a short-duration shock pulse, the actuator can be used in a two-sled impact test mode. In this method the actuator imparts a velocity to the first sled which impacts a second sled via a mechanism that controls the forces between the sleds. Up to

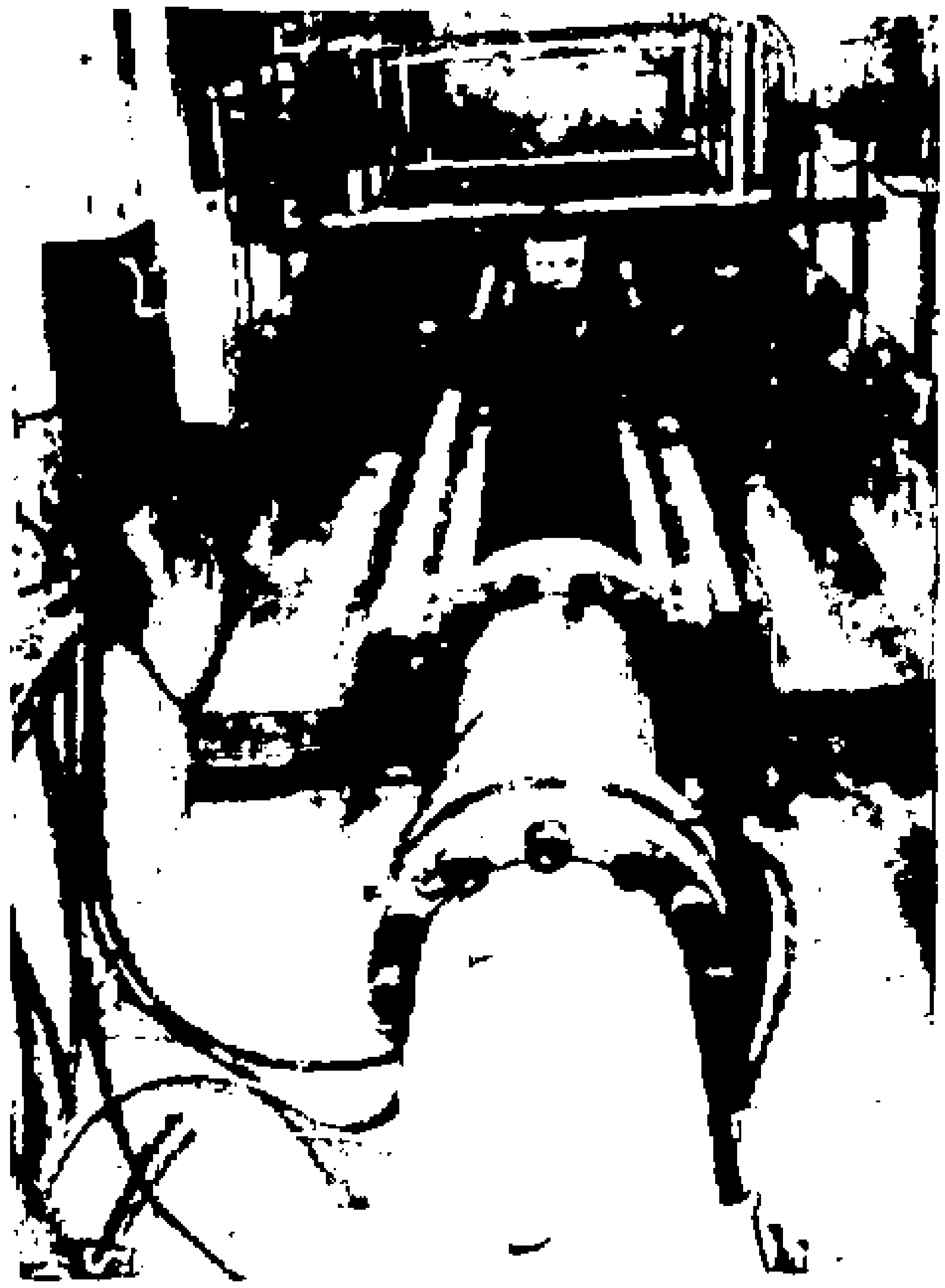


Figure 3   Pneumatic actuator facility

10,000 x gravity can thus be applied to a test specimen on the second sled. Other test methods involving multiple sleds and force programmers have been developed to simulate various field environmental conditions.

Item 4.   *Explosively Propelled Flyer Plates*

Studies of the effects of oblique impact on the structural integrity of complete systems, or of nonplanar stress waves or joint response, and many other experiments in which objects are subjected to nonsimultaneous loading conditions can be conducted using massive flyer plates of plastic or metal accelerated by solid explosives to high velocities with low rotational rates. A test specimen can be positioned at any point along the flight path to allow the plate to rotate the desired amount before impact. Thus any angle between the velocity vector and surface normal may be obtained to simulate oblique impacts. Plates weighing up to [illegible] kg have been employed at velocities from 1.5 to 4.0 mm/μs.

ENVIRONMENTAL SIMULATION

Item 5. *Centrifuge Impact*

The energy absorbing capabilities of insulation material can be evaluated using the 10.7-metre-radius centrifuge. A test specimen is secured to the end of the centrifuge arm by a cable. When the centrifuge is stabilized with the specimen traveling at the desired impact velocity, the cable is cut, allowing the specimen to travel freely into a 14,000-pound steel target. Hardwire instrumentation is used to measure deceleration forces on the specimen during impact.

The facility can provide impacts from 10 to 550 ft/s, *with a maximum velocity of 210 ft/s on a 10,000-pound* test specimen.

Item 6. *Blast Testing*

The effect of a blast-wave environment enveloping a structure (tank, car, building, reentry vehicle) can be studied using a shock tube to produce the desired shock wave. One such tube is 1.8 metres in diameter and 60 metres long, with a driving charge of high explosives at one end and the experiment at the other. Detonation of the explosive produces an aerodynamic shock wave which moves down the tube to envelop the experiment (Figure 4). In a typical experiment, a charge of 150 kg of PETN explosive in the form of primacord is used in the shock driver section at a loading density of 11 kg/m³. At this density, the explosive energy is contained by *the driver.*

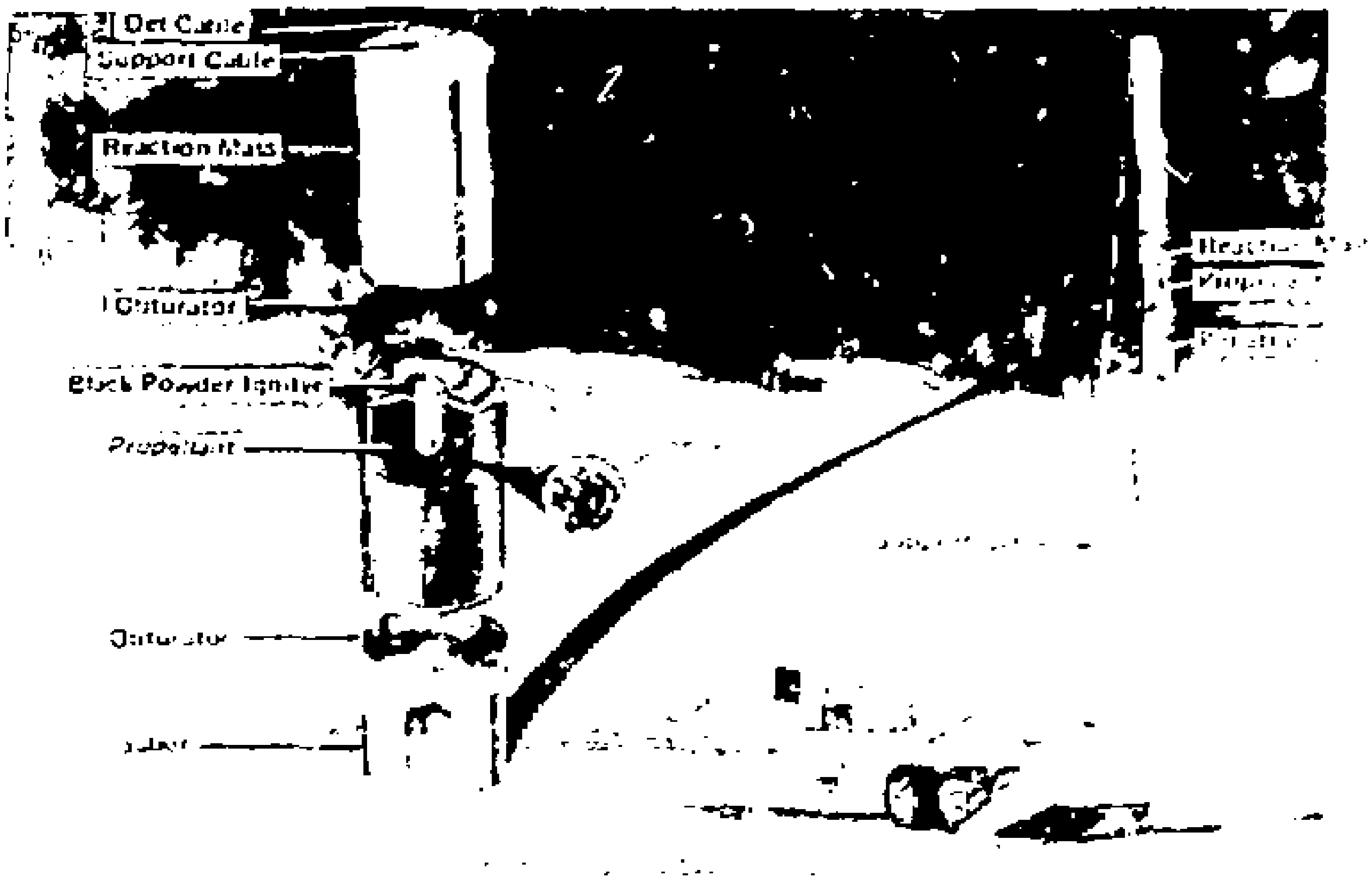
Blast overpressures of 1.4 MPa and 0.5 MPa can be generated in the 1.8-m and 5.8-m test sections, respectively. Other shock tubes up to 2 m in diameter are available for generating blast pressures up to 4 MPa. These, however, are driven by larger explosive charges with energy densities that cannot be contained. Thus, a driver section must be expended with each test.

Item 7. *Earth Penetration Testing*

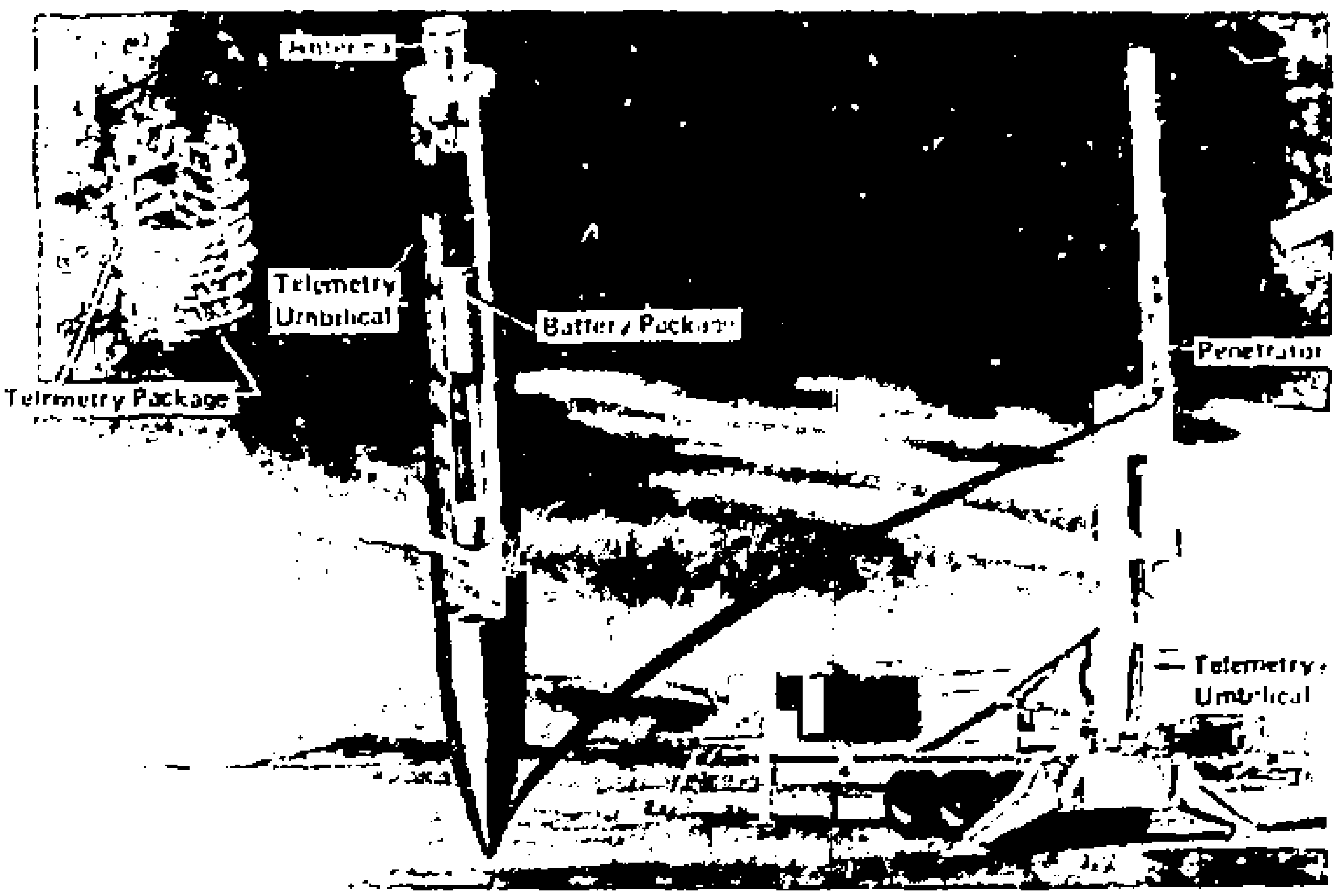
Terradynamics deals with the motion of soil and other solid materials, and with forces acting on bodies in motion relative to those materials. Terradynamics studies have resulted in analyses of earth penetration, and a field test program that has yielded projectile deceleration-time data and penetration performance in materials ranging from saturated clay to competent limestone. Projectile penetration can be used for environmental testing of components. The penetration event can generate high-deceleration long-time duration loading profiles that cannot be attained in the laboratory. Current capabilities consist of air launch at free-fall and boosted velocities, track launch and horizontal impact up to 1.2 km/s (4000 fps), and portable recoilless-gun accelerators.

The Davis Gun, a smooth-bore recoilless reaction-mass gun, can be used to fire a 304.8-mm (12-inch)-diameter instrumented projectile vertically downward into man-made or earth targets at velocities to 457.3 m/s (1500 fps) [for a 455-kg (1000-lb) penetrator] or 914.6 m/s (3000 fps) [for *a 136-kg (300-lb) penetrator*] *(Figure 5a and b). The air* gun can vertically launch 76.2-mm (3.0-inch)-diameter, 6.14-kg (13.5-lb) instrumented projectiles into man-made or natural earth targets at velocities to 198 m/s (650 fps). A 25.5-kg (56-lb) projectile can attain velocities to 99 m/s (325 fps).

Figure 4. Blast testing of a missile system in a shock tube



a. Earth penetrator propulsion system



b. Earth penetrator

Figure 5. Terradynamic earth penetrator systems

ENVIRONMENTAL SIMULATION

Item 8 *Programmed Transient Testing*

Computers are used to program transient acceleration tests on vibration machines. Typically, a desired environment is defined as a shock spectrum or a specific time history representing the environment in which the specimen will be used or a combination of damped sinusoids. The computer is used to generate the excitation transient including corrections to bring the final velocity and displacement to zero so that physical constraints imposed by the exciter are met with minimum distortion of the desired transient. Typical of simulated field shocks are missile stage separation, parachute ejection, and handling and transportation environments.

A computer is used to replace the trial-and-error approach of successive approximation with comparison of *output-to-input by transfer functions. As applied, the* computer generates a known calibration pulse into the electronic amplifier, monitors the test input point acceleration, does a complex Fourier analysis of both, calculates a complex transfer function in the frequency domain for the complete system, and applies the inverse transfer function to the desired output to arrive at a corrected input time domain excitation that will generate the precise desired test acceleration input. The computer is then used to evaluate the test at various locations on the specimen. Plotted analytical results can be presented in near-real time as transfer functions between any two points, and shock or Fourier spectra versus frequency in two dimensions or, where appropriate, also against time in three dimensions. Setup, test, and analysis are based upon a sound theoretical approach using the capabilities of the digital computer; as a result, relatively inexpensive tests can be conducted with short turnaround times.

Item 9. *Computer-Controlled Shock Testing*

Data acquisition and analysis capabilities have been instituted to improve data quality and turnaround time of shock testing. Control of all parameters, data annotation, and test setup can either be done remotely at the test facility or in the computer room via a computer display terminal featuring interactive graphics and a hard-copy unit. A 32-thousand core disc-based minicomputer system can take up to eight channels of analog data directly through its 200-thousand words per second analog-to-digital converter on disc or can digitize any number of channels from analog magnetic tape recordings. Data are presented as complete annotated plots of original pulse and velocity change versus time; complex Fourier spectrum, shock spectrum, complex transfer function versus frequency, and special data desired by the test requester such as strain versus displacement.

Item 10. *Magnetically Driven Flyer Plates*

Surface impulse can be applied to structural shapes with magnetically driven flyer plates. Energy up to 750 kJ stored in capacitor banks is used to propel the plates. Cylindrical or conical structures with base diameters of ~0.4 m can be laterally impulse-loaded up to ~1200 Pa·s. Typical measurements include strain, acceleration, displacement, and high speed photographic coverage.

Item 11. *Impulse Simulation*

A technique for simulating transient surface-loading effects uses the light-sensitive explosive silver acetylide silver-nitrate, which can be spray-painted on any surface. The desired explosive distribution is obtained by spraying through a mask and rotating the specimen between spray passes. The explosive is detonated by an intense flash of light. Extremely thin layers of explosive can thus be detonated simultaneously.

The test facility permits the remote handling and firing of a 1-kg explosive charge sprayed over a 1-m² surface. Impulse levels may range from 10 Pa to over 1000 Pa with load rise times of ~1 μs. Strain, acceleration, displacement, x-ray, and high-speed camera measurements are obtained. Equipment for recording 80 data channels is available. Spray-painted explosives are particularly useful for structures with irregular surfaces or where step discontinuities in impulse complicate loading.

Item 12. *Random-Vibration Testing*

Since random-vibration testing is computerized for improved control accuracy, the time required for preparing a test is reduced. Side advantages of considerable significance are the near real-time data analysis and the power spectral density plots obtained. Control spectra may be of any form that can be represented by straight-line segments and may range from 0.5 Hz to over 3 kHz with rms forces of up to 155.7-thousand Newtons (35,000 pounds) and displacements to 200 mm (7.87 inches) at the low frequencies. The computer systems function with up to 1024 discrete frequency lines in either pseudo or true random mode. Capability is available on the minicomputer system to perform spatial modal analysis resulting in eigenvector or eigenvalues at monitored points. This technique allows development of mathematical models of a subsystem package.

Item 13. *Acceleration and Deceleration Simulation*

The centrifuge-computer combination facility is an automated, precise, accurate, and very repeatable system designed for the test of inertial devices. Performance is optimized for the test of 4.5-kg (10-lb) packages at a radius of 0.6 m (2 ft), but much heavier devices can be tested at radii up to 0.9 m (3 ft). Peak speed is 52 rad/s (500 rpm).

The system can provide controlled rates from 0.1 mm/s^3 (0.00062 g's) linear ramps to the worst expected reentry condition. Standard software allows the generation of polynomials up to order 6 and linear ramps through computerized commands. Nonstandard programming can be written if required for either control or data analysis.

Up to eight switch functions can be monitored by the computer with the acceleration at function times measured with accuracies of five significant figures. Repeatability of the time profile can be as good as 1 ms in a 10-s program. Acceleration/time integrals can be measured with 0.1 percent accuracy. Test environments from 200 K (-100°F) to 366 K (+200°F) are available with no degradation specifications.

Item 14. *Vulnerability of Structures to Airborne Objects*

A test facility used to evaluate the vulnerability of structures to tornado-borne objects has been completed and evaluated. Among objects successfully thrown at the structure are 12-foot x 4-inch x 12-inch wooden planks at 200 mph; 3-inch-diameter pipe 10 feet long at 100 mph, and a 3000-pound car at 50 mph.

The capability of the facility includes subjecting concrete slabs 17 by 17 feet square, and up to 24 inches thick, to the impact of tornado-generated missiles of any variety. For instance, telephone poles at velocities at 150 mph, pipe to 300 mph, planks to 300 mph, etc., can be accelerated into concrete slabs or any other material (Figure 6).

Item 15. *Water Testing*

A test series was conducted using the maximum capabilities of the water impact facility to experimentally determine the submarine trajectory of a weapon entering the water at a 30-degree angle of attack, a pitch angle of 10 degrees, and a velocity of 400 fps, while spinning at 20,000 rpm. The model ... was 1/5 scale.

Figure 6. Automobile impact into a concrete wall

A turnaround water-impact test technique has been developed using the rocket sled to accelerate a water tank up to velocities of 609.8 m/s (2000 fps) prior to impact with full-scale systems. Water tunnel (Figure 7) capabilities include velocities up to 167.7 m/s (550 fps) in a 152.4-mm (6-inch)-diameter test section. Test duration is approximately 5 seconds. Force, and pressure measurements are possible within the test section and photographic coverage of the test specimen is available. Models up to 15.88 mm (5/8 inch) in diameter can be used for drag, cavitation, and underwater cavity analyses.

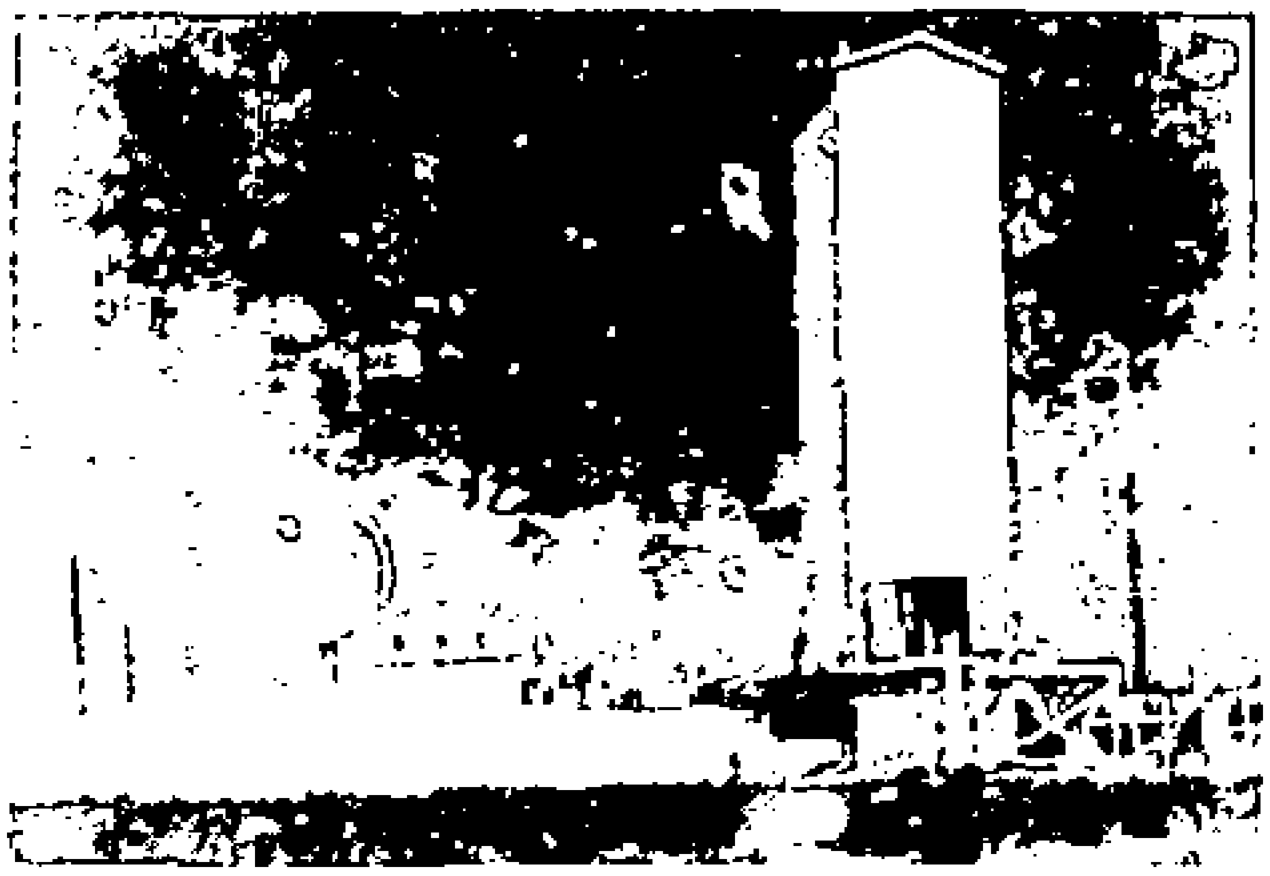


Figure 7. Vertical water tunnel

ENVIRONMENTAL SIMULATION

Radiation Loading

Facilities have been developed for producing various forms of radiation in which to investigate the response of materials, components, and systems. Combined or isolated levels of neutrons and gamma rays are obtained from pulse nuclear research reactors; steady-state gamma rays are produced by cobalt and cesium sources; Bremsstrahlung x-rays and electron beams are generated by pulse accelerators; thermal loading is produced by a radiant heat facility, and various sources of low-level electromagnetic energy are used. The radiation fields and their effects are defined by radiation and beam transport studies and measured by appropriate instrumentation. The facilities are used in support of nuclear weapon studies, nuclear reactor safety research, and nuclear fusion research using lasers and electron beams to generate the required physical conditions.

Pulse Reactors

Pulse reactors are designed to produce bursts of high-intensity neutrons and gamma rays. Experimental techniques and instrumentation are developed to study the response of electronic circuits, structures, and materials including fissionable and explosive materials. The facilities are also used to produce neutrons for radiographic evaluation of components and for simulating conditions for studying the response of nuclear-power reactor components to abnormal transient conditions. (Items 1-5)*

Current Capabilities

Annular core pulse reactor (ACPR)
- Pulse mode
  - 4.7-ms pulse width (FWHM)
  - 1.3-ms initial power transient
  - 1.7×10^{15} n/cm², E > 10 keV
  - 10^{6} rad (H_2O) gamma dose/pulse
  - 9-inch-dia x 12-inch-high irradiation cavity
- Steady-state mode
  - 300 kW steady-state power (600 kW approval expected)
  - $5 \times 10^{[illegible]}$ n/cm²/s, E > 10 keV

Neutron radiography
- 10^{8} n/cm² s thermal at maximum steady-state power
- 3×10^{9} n/cm² thermal in pulse mode
- 65 to 500 L/D ratios

Sandia pulse reactor (SPR) II
- Metal core, ha[illegible] energy spectrum (350 keV p[illegible]
- 1.5-inch-dia x 8-inch-high central irradiation cavity
- 1×10^{15} n/cm², E > 10 keV
- 40-μs pulse width (FWHM)
- 2×10^{5} rad (H_2O) gamma dose/pulse
- 3 kW steady-state power

Sandia pulse reactor (SPR) III
- Metal core, hard energy spectrum (350 keV peak)
- 7-inch-dia x 12-inch-high central irradiation cavity
- 1×10^{15} n/cm², E > 10 keV
- 40 μs pulse width (FWHM)
- 2×10^{5} rad (H_2O) gamma dose/pulse
- 15-kW steady-state power

Pulse Accelerators

These accelerators are used to generate intense short pulses of ionizing radiation for the study of the transient effects of x-rays on electronic components and circuits, permanent radiation damage to electronic devices and circuit parts, and the responses of nonconductors. Also studied are the thermomechanical responses of materials and structures through melting and vaporization, and radiation-induced changes in the physical structure of materials. The accelerators are also used to generate electron beams for producing fusion, pumping gas lasers, and heating plasmas. (Items 6,7)

*See Highlights, below.

Current Capabilities

Source	REBA*	Hermes II	Hydra*
Bremsstrahlung Mode			
Energy (MeV)	3.0	10.0	0.9
Pulse width (ns)	50	60	100
Dose (krad)	15	50 (300)**	5 cal/g
Dose rate (r/s)	3×10^{11}	8×10^{11} (6×10^{12})**	–
Area (cm²)	50	300 (20)**	5
Electron Beam Mode			
Energy (MeV)	3.0 (1.0)**	10.0	0.9
Fluence (cal/cm²)	400 (300)**	700	400
Dose (cal/g)	400 (1000)**	300	2000
Area (cm²)	3 (3)**	15	5

*REBA — Relativistic Electron Beam Accelerator. Hermes II and Hydra — Electron-beam accelerators; for further detail see Physical Sciences, SAND74-0074.

**Alternate mode of operation.

Steady-State Sources

Steady-state neutron and gamma irradiation facilities and associated experimental techniques and instrumentation support studies of radiation effects in electronic components and circuits, biological effects of radiation, gamma sterilization, and other programs for which an intense neutron or gamma source is required. (Item 8)

Current Facilities

- Gamma irradiation facility (GIF)
  - Cobalt and cesium gamma sources
  - 10^3 to 2×10^5 rad (H_2O)/min peak rates
- Neutron generator

Thermal Testing

High-temperature facilities have been developed to study thermal loadings of materials, components, and systems. Temperature profiles can be simulated using tungsten filament quartz-tube lamps or graphite resistance heaters. Earth orbital decay reentry heat-transfer conditions can be simulated in the arc tunnel with accurate duplication of stagnation enthalpy and reentry pressure profile. Solar heating can be simulated with either tungsten-filament lamps or carbon-arc devices, which provide a close spectral match where absorption and reflection properties are important. (Items 9,10)

Current Facilities

- Radiant heat
- Arc tunnel
- Ovens
- Climatic chambers

Electromagnetic Testing

Electromagnetic radiation testing is used to investigate the effects of communication and radar transmissions on electrical systems. Low-level radiation facilities have been developed to establish the transfer functions between incident and induced electromagnetic fields or currents in cables inside electrical systems. In addition, laboratory techniques have been developed to induce system failure by direct illumination of electronics packages. The combination of the radiation-facility-measured transfer function and the laboratory-induced failures provides sufficient information to certify electrical systems.

Electromagnetic pulse testing is the basis for studies of the effect of electromagnetic energy generated by direct transient radiation on electrical components. The high currents induced by the rate of change of the transient radiation pulse are capable of burning out discrete components in electrical systems. Both facilities and laboratory techniques have been developed to investigate this transient failure mechanism in electrical systems.

Current Facilities

- Electromagnetic radiation
- Electromagnetic pulse
- Lightning
- Static electricity

ENVIRONMENTAL SIMULATION

HIGHLIGHTS

Item 1. *Annular Core Pulse Reactor (ACPR)*

The ACPR (Figure 1) provides high radiation levels for the study of both steady-state and transient irradiation effects. A large central cavity allows in-pile testing of most full-size assemblies; maximum-yield pulses can be obtained at 20-minute intervals. Radiation experiments on electrical components have been conducted. A program of reactor safety studies is under way with emphasis on uranium dioxide equation-of-state analysis.

Figure 1. Reactor core for the annular core pulse reactor (ACPR)

Item 2. *Sandia Pulse Reactor II (SPR II)*

SPR II (Figure 2) is used in a variety of basic and applied research programs including radiation effects in materials and electronic devices; dynamic response of composite materials; pulse reactor fuel-material studies; neutron-pulse laser systems; electrical component response and degradation tests. Maximum-yield pulses can be obtained at 1-1/2 hour intervals.

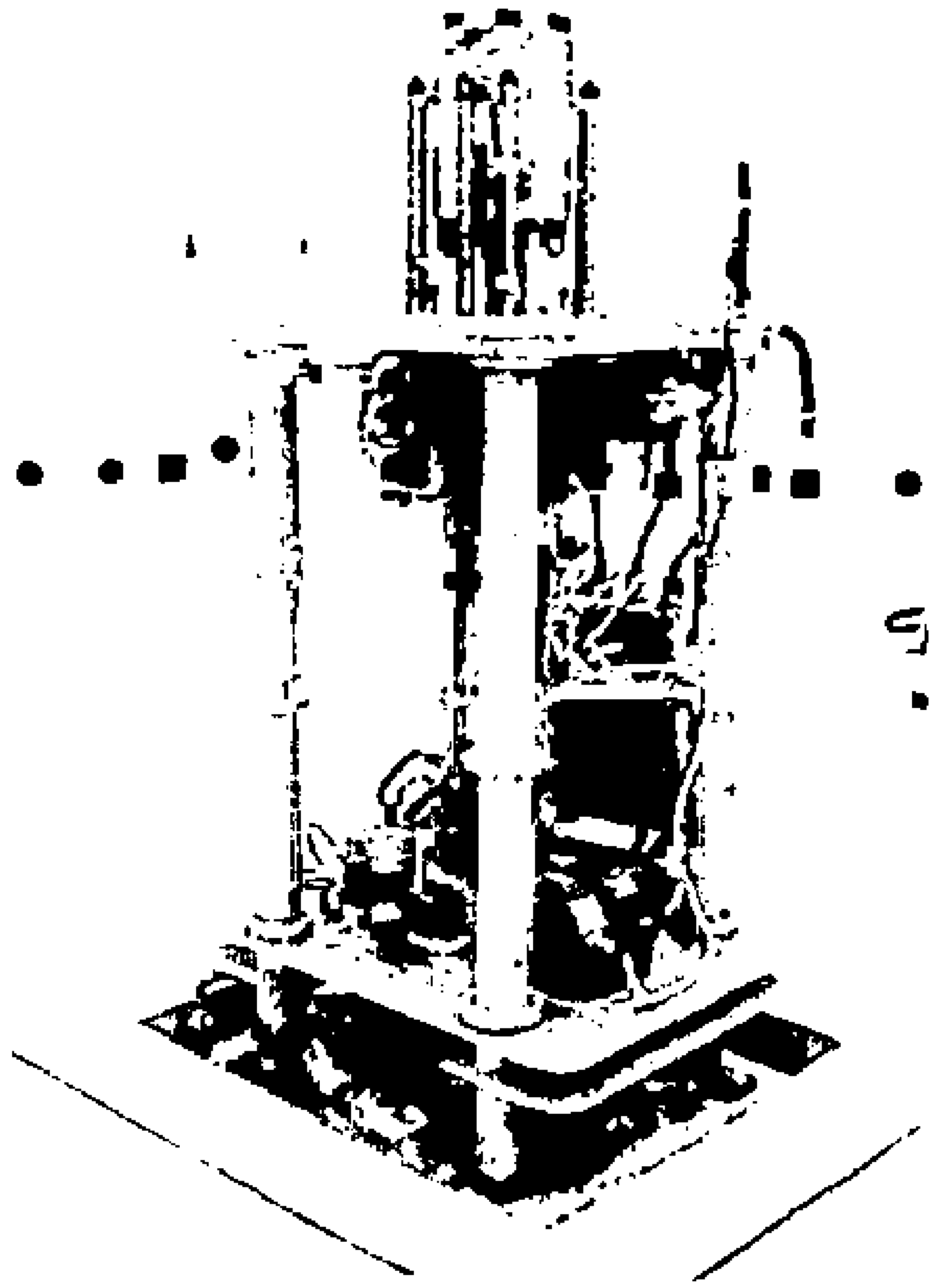


Figure 2. Sandia Pulse Reactor II (SPR II)

Item 3. *Reactor Fuel Metallurgy and Chemistry*

Investigation of failures of Sandia Pulse Reactor (SPR II) components revealed a number of problem areas which alone or in combination contributed to the failures and reflected inadequate or no controls in fabrication of the components. Faults included casting voids, incomplete alloying, and high impurity content, primarily of carbon. In particular, it was concluded that cracking of the fuel plates was caused by the almost continuous brittle grain-boundary phase identified as uranium carbides. Information obtained from the studies has been used to design the next generation of pulse reactors.

Item 4. *Quality Assurance*

A quality-assurance program is applied to the design, fabrication, construction, and testing of all new structures, systems, or components required for a new pulse reactor facility, and to modifications of existing structures, systems, and components. Requirements imposed by the Quality Assurance program apply to all activities affecting the safety-related function of these structures, systems, and components, including design, procurement, fabrication, handling, shipping, storing, cleaning, erecting, installing, inspecting, testing, operating, maintaining, repairing, refueling, and modifying. The program comprises all planned and systematic actions necessary to provide confidence that the reactor can be safely operated and maintained.

Item 5. *Nondestructive Testing*

Neutron radiography is used to investigate explosive-component development and to complement x-radiography. Separations of dissimilar explosive materials, as well as cracks, voids, bridgewire failures, and nonpropagating detonations, are evaluated with resolution to 1 mil. Other applications include the use of hydrogenous materials or materials with high thermal neutron cross sections placed inside high-Z containers for the purpose of detecting broken, displaced, or missing material. Pulsed neutron radiography (motion picture) capabilities are developed to investigate the transient mixing behavior of gases at high pressures and to observe detonating and propagating explosives. Activation analyses of isotopes in the central cavity and in the pneumatic shuttle system are techniques developed to investigate isotopes of long and short half-lives, respectively. Typical irradiation under various neutron spectra ranges from 10^{14} nvt to 1.0 to 10^{17} nvt steady-state accumulation and to 3×10^{15} nvt pulsed.

Item 6. *Accelerator Applications*

Radiation effects in materials and components are studied extensively using pulse accelerators. Areas investigated include transient effects in devices and components ranging from photo-current measurements in discrete components to induced electromagnetic pulse effects in circuits and components, and permanent effects in devices caused by such phenomena as trapping of liberated charge carriers at surfaces and interfaces. Use of accelerators in the e-beam mode has made possible studies of the transient thermomechanical response of solids subjected to high-intensity, short-duration energy deposition as well as permanent damage to a material or structure resulting from spall, delamination, and blowoff of surface material.

Item 7. *Diagnostics Development*

Specialized diagnostic tools and techniques have been developed to characterize radiation fields (i.e., neutrons, gamma and x-rays, electrons, and positive ions). This effort has included the development and use of magnetic spectrometers to measure electron and photon spectra, and a specialized device to measure electron spectra on the pulse accelerators. Other techniques used to measure radiation environments are solid-state and photon-recoil spectrometers, active neutron and photon detectors (photodiodes, p-type intrinsic n-type detectors), Compton diodes, scintillator/photomultiplier detectors, fission-couple detectors (foil activation techniques, thermoluminescent detectors, and plastics/glasses). Also included has been the development of calorimetric techniques for e-beam and photon definition, as well as Rogowski coils, B_θ probes, current shunts, and capacitive and resistive voltage dividers to monitor e-beam characteristics.

Item 8. *Gamma Irradiation Facility (GIF)*

The GIF contains two independent shielded cells containing a 10^5 Curie ^{60}Co source and a 2×10^5 Curie ^{137}Cs source. The facility has been used extensively in radiation-effects studies as well as in programs dealing with sterilization techniques for blood, milk, and sewer wastes.

Item 9. *Radiant Heat Facility*

The radiant heat facility provides a means of conducting controlled high-intensity transient heat input testing of full-scale units by regulating the electrical power fed to radiant-heat emitters. The facility consists of power controller units, power transformers, programmer computer units, control consoles, data recorders, and heater assemblies. The heater assemblies are infrared heat lamps and graphite radiators in various configurations.

Test space available	500 ft²
Access door opening	10-ft wide x 12-ft high
Programmed specimen temperature range	200 to 2800 F
Programmed specimen heat flow range	0 to 500 Btu/ft²·s
Peak controlled heater power	19,200 KW (20 s)
Minimum rise time to full power	2 seconds
Output voltages available	[illegible], 600, 480, 240, 120 V
Explosive limits	Only self-contained HE units allowed

ENVIRONMENTAL SIMULATION

For testing smaller units, a portable radiant-heat cabinet is also available which may be precisely controlled at low power.

Item 10. *Reentry Heating Simulation*

An arc-tunnel facility has been used to generate high *temperatures at high heating rates (311 to 811 K/s; 100 to* 1000 F/sec) for the evaluation of high-temperature insulation used in advanced reentry vehicles. Performance of the insulation is both time- and temperature-dependent. Insulation samples were sandwiched between a graphite disc 3.18 mm (1/8 inch) thick, heated by the arc jet, and an aluminum disc simulating the reentry vehicle substructure. The complete reentry heating profile was simulated by testing in an argon jet to achieve heating rates encountered during the laminar flow regime, then the jet was switched to nitrogen and the power level increased *to simulate transition to turbulent-flow heating rates.* Temperatures were measured at the front and back faces of the insulation during the test.

RESEARCH, DEVELOPMENT, AND EVALUATION TESTING

In a number of technical disciplines test facilities are used concurrently for experimental research, the development of advanced engineering hardware, and design evaluation. Such is the case with facilities used in the aeroscience, material-response, and nondestructive-testing technologies.

Aero Testing

Facilities developed for aerospace testing include wind tunnels, plasma jets, shock tubes and flight simulators. Full-scale flight vehicles are used to achieve certain test conditions.

Wind Tunnels

Wind tunnels are used to determine aerodynamic characteristics of flight vehicles and to investigate complex flow phenomena. Facilities include a trisonic wind tunnel in which the test section is 30 x 30 cm, and a hypersonic wind tunnel with a test section 45 cm in diameter. Flow Mach numbers of 0.7 to 14.0 can be obtained. Instrumentation includes precision strain gage balances, pressure transducers, heat-transfer gages, displacement indicators, shadowgraph optics, electron-beam devices and hot-wire probes. Data are recorded and operations controlled by a high-speed data acquisition and control system. (Item 1)*

Current Activities

- Scaled-model tests
  - Force and moment
  - Pressure distribution
  - Heat transfer
  - Flow-field definition
  - Dynamic stability
- Hypersonic boundary-layer studies
- Instrumentation development

Plasmajets

Plasmajet equipment provides conditions of stagnation enthalpy and pressure that simulate the aerothermodynamic environment encountered by reentry vehicles. The Laboratories' 5-megawatt facility can provide total enthalpies from 5 to 50 kJ/g depending upon nozzle, stagnation pressure, and type of arc heater. Similar enthalpies can be obtained with the 2 megawatt facility; its nozzles are smaller, but maximum stagnation pressure is an order of magnitude greater. (Item 2)

Current Activities

- Material ablation and development tests
  - Nosetip
  - Aft heatshields
  - Antenna windows
- Radio frequency propagation studies
- Flow diagnostics

Shock Tube

Shock tubes are used in molecular laser studies. The 500-kilojoule arc-driven tube can provide shock-wave velocities up to 15 km/s into a 1-Torr test gas. The driven section is 30 cm in diameter by 11 metres long. The driver has an inside bore of 10 cm and a maximum arc length of 77 cm.

Current Activities

- High-temperature chemical kinetics
- Blast-wave physics

Flight Simulators

Analog and hybrid (analog/digital) computer equipment is used to simulate flight characteristics. This equipment can be interfaced to three-axis angular-motion simulators on which hardware is mounted and subjected to the angular velocities and accelerations experienced in flight. (Item 3)

*See Highlights, below.

RESEARCH, DEVELOPMENT, AND EVALUATION TESTING

Current Activities

Six degree of freedom flight simulations
Guidance and control system development
Component testing in real time

Flight Test Vehicles

Special-purpose flight vehicles are developed to complement ground-based facilities in order to achieve certain test conditions. Depending on conditions desired, these vehicles are rocket-boosted, dropped from aircraft, or launched from sleds or guns. (Item 4)

Current Activities

Flight configuration studies
- Stability
- Performance
- Guidance and control

Parachute deployment studies
Boundary layer transition studies
Reentry vehicle heatshield development
Nosetip-erosion investigations

• • • • • • *HIGHLIGHTS* • • • • • •

Item 1. *Scaled-Model Tests*

Wind-tunnel facilities complement analytical and numerical methods in the determination of aerodynamic forces and moments acting on flight vehicle configurations. Shown in Figure 1 is a high-performance sounding-rocket model installed in the trisonic wind tunnel. Aerodynamic loads imposed upon the model during tunnel operation are measured by a precision strain-gage balance positioned within the model.

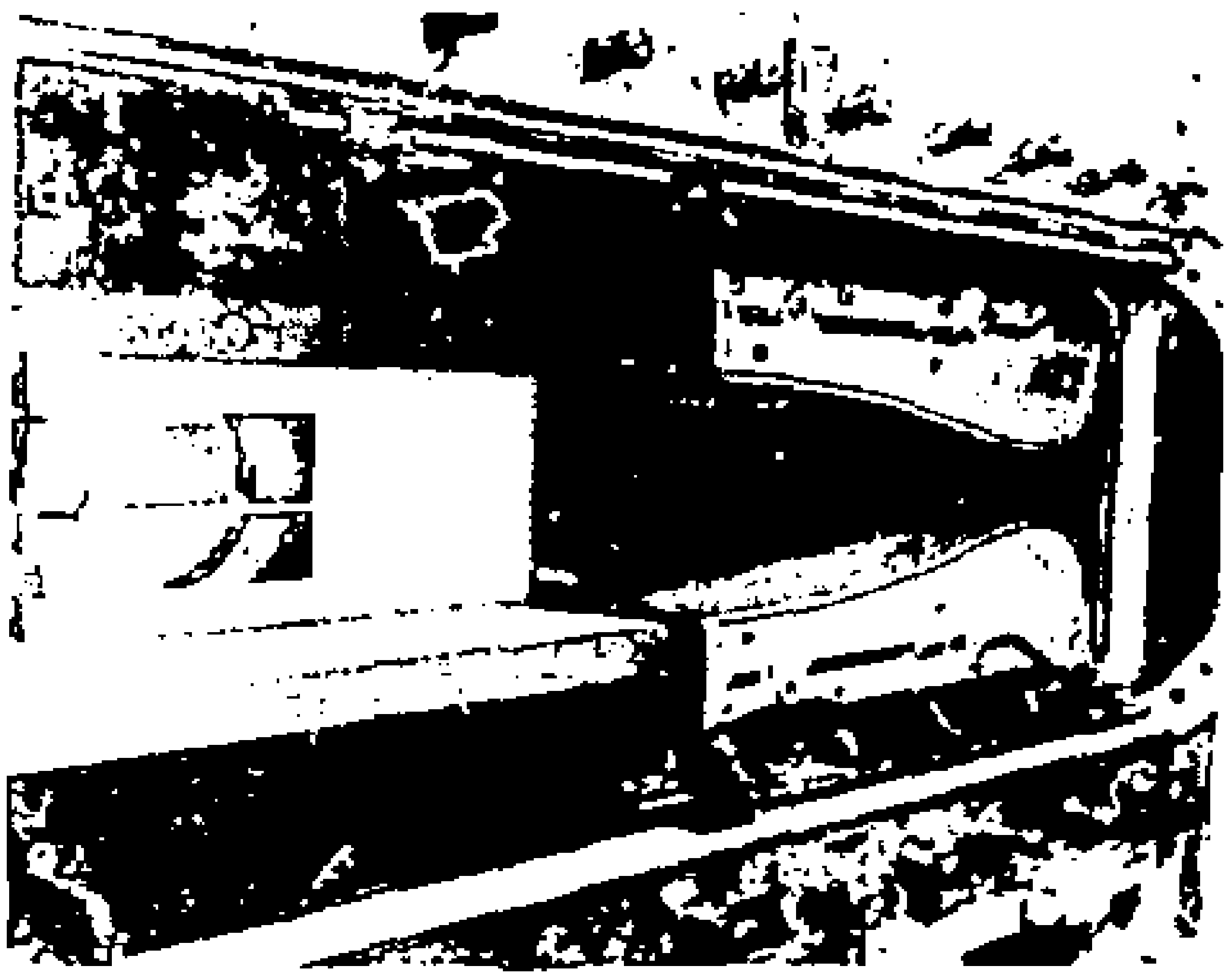


Figure 1. Trisonic wind tunnel

Item 2. *Material Ablation Tests*

An example of ablation testing in the 5-megawatt plasmajet facility is illustrated in Figure 2. In this test, reentry-vehicle nosetip material is subjected to plasma flow with an enthalpy of 45 kJ/g and stagnation pressure of 0.1 atm.

Figure 2. Ablation test in 5-megawatt plasmajet

Item 3. *Flight Control Hardware Testing*

Control systems are designed to provide missile configurations with prescribed maneuvering capability. Before flight, the control hardware package is tested on the Carco three-axis flight-motion simulator as shown in Figure 3. The simulator is driven by an appropriately programmed hybrid computer linked to the control hardware.

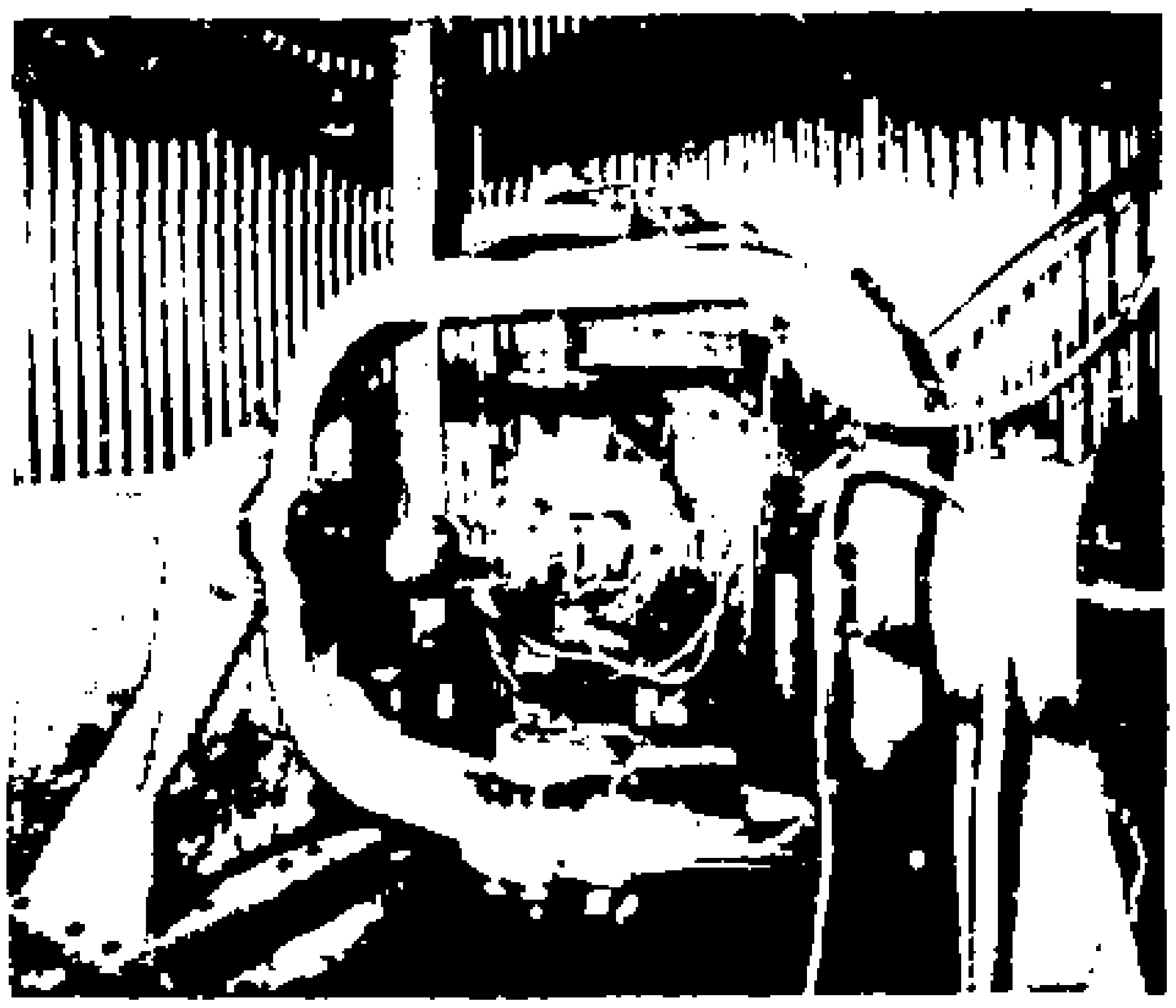


Figure 3. Control system test on motion simulator

Item 4. *Parachute System Proof Tests*

Weapon parachute systems are designed to operate without failure at a dynamic pressure 25 percent greater than the maximum operational level. To proof-test at this condition, rocket-boosted parachute test vehicles are used. The vehicle shown in Figure 4 was designed to test deployment of a 5.2-meter-diameter ribbon parachute at a dynamic pressure of 130,000 newtons per square meter.

Figure 4. Parachute test vehicle

RESEARCH, DEVELOPMENT, AND EVALUATION TESTING

Material Response

Facilities exist to measure mechanical and thermal response of materials over wide ranges of temperatures, pressures, and loading rates to satisfy the needs of component and structural design evaluation. In addition to conventional mechanical testing including creep, stress relaxation, cyclic fatigue, static loads, and high strain rates over a wide temperature range, specialized test techniques and instrumentation have been developed for high pressures, combined stresses, very high temperatures, and extreme strain rates. Ultrasonic test facilities are used to determine sound velocities to high temperatures and pressures, and to determine accurate dispersion and attenuation curves for very lossy materials. Thermal capacity, diffusivity, and emissivity tests can also be made over a wide temperature range. Special capabilities have been developed to measure material responses at extreme pressures and temperatures using precision high-velocity impacts, high-power pulse lasers, and large pulse electron-beam machines.

Dynamic Mechanical Properties

A plate-impact test has been developed, together with high-resolution instrumentation, to provide quantitative data for material response at the highest strain rates that can be sustained in materials. A variety of compressed-air and propellant-driven gun facilities permits launching of flat flyer plates for planar impact against stationary target plates. Quartz stress gages or laser interferometers capable of nanosecond time resolution allow measurement of the fine structure of loading shock waves and unloading release waves from which dynamic yield strengths, relaxation spectra, polymorphic phase-change kinetics, melting kinetics, high-pressure equations of state, and dynamic spall fracture data are deduced.

A variety of ultrasonic test facilities provides routine sound-speed measurements over wide ranges of temperature and pressure. Both pulse echo and interferometric methods can be used. In addition, facilities have been developed with the wide frequency and high powers necessary to accurately determine dispersion and absorption curves for lossy materials. These have been used successfully with porous materials, polymers, and laminated and fibrous composites. (Items 1,2)*

Current Facilities

Gun driven flyer-plate facilities
- Impact velocities to 5 km/s
- Strain rates to 10^8/s
- Shock pressures to 1.0 TPa
- Shock temperatures to 10^4 K

Ultrasonic facilities
- Low temperatures to 1 K
- High temperatures to 600 K
- Static high pressures to 3 MPa

*See Highlights, below.

Static Mechanical Properties

Facilities have been developed for testing materials under states of combined stress. Static or low-rate tests involving biaxial stresses (via tension or compression, external or internal pressurization, and torque loading of tubular specimens) are applied to materials such as structural metals to determine combined stress-yield surfaces, and to composites to determine combined stress-failure envelopes. Static or low-rate confined compression tests, involving so-called triaxial loading within a static high-pressure vessel, have been applied to measure failure envelopes and strength of rocks. Both biaxial and triaxial machines have computer feedback control, allowing sophisticated programming of loading paths as well as direct computer-controlled data acquisition and reduction. (Item 3)

Current Activities

Biaxial facilities
- 800 kN end load
- 70 MPa pressure
- 8 kN-m torque

Triaxial facilities
- 1.8 MN end load
- 1.0 GPa pressure

RESEARCH, DEVELOPMENT, AND EVALUATION TESTING

Thermal Mechanical Properties

Test capabilities exist for determining all conventional mechanical properties and some unconventional ones. Creep and stress relaxation tests can be made on metals, polymers, ceramics, and composites under controlled temperature and atmosphere environments. Conventional uniaxial stress-strain properties can be obtained at temperatures from that of liquid nitrogen to the melting points of refractory metals. In addition, feedback-controlled, time-dependent thermo-mechanical environments can be applied to electrically conducting materials during which mechanical properties can be obtained as a function of the history of temperature and stress or strain.

Stress-corrosion cracking tests are performed in a variety of environments with controlled humidity and in pressurized liquid. These can also be used in fracture-mechanics studies except for molten salts and pressurized liquids. (Item 4)

Current Facilities

- Uniaxial loading facilities
  - Load - 800 kN
  - Strain rate - 10^{-5} to 10^{2}/s
  - Temperatures - 65 to 3000 K
  - Pressures - 10^{-6} Pa to 150 MPa

Thermal Properties

Techniques and facilities have been developed for obtaining data on various thermal properties required for system design and application. A major feature of these facilities is their capacity to make rapid measurements on a large number of samples and a wide variety of materials. Current studies involve determining thermal diffusivities, specific heats, and optical properties of molten refractory materials. Studies are also under way on optical and radiative properties.

Current Facilities

- Thermal conductivity
- Thermal diffusivity
- Thermal expansion
- Enthalpy and specific heat
- Optical absorptance, reflection, and transmission
- Total hemispherical emittance

• • • • • • *HIGHLIGHTS* • • • • • •

Item 1. *Interior Ballistics of Two-Stage Light Gas Gun*

Experiments to measure projectile velocity-time histories in a two-stage light gas gun during launch have been made using a Sandia-developed instrument that measures velocity by laser interferometer. Two sample velocity-time histories for identical gun loadings in Figure 1 illustrate the essential features and demonstrate experimental reproducibility. The interferometer is capable of an accuracy with 0.1 percent of the final launch velocity, which in Figure 1 is close to 5 km/s, and a time resolution of 5 µs for the entire launch duration, which in this case was in excess of 2 ms. The inset shows the early portions of the records on an expanded time base, which exhibit discrete steps because of shock reverberation in the propellant gas. Direct measurement of projectile velocity with unusually high accuracy, together with fine time resolution for an extended recording time, has added a valuable new tool for the detailed study of interior ballistics. For example, it is possible to observe projectile failure in the gun tube during launch, and deduce precise conditions under which failure occurs.

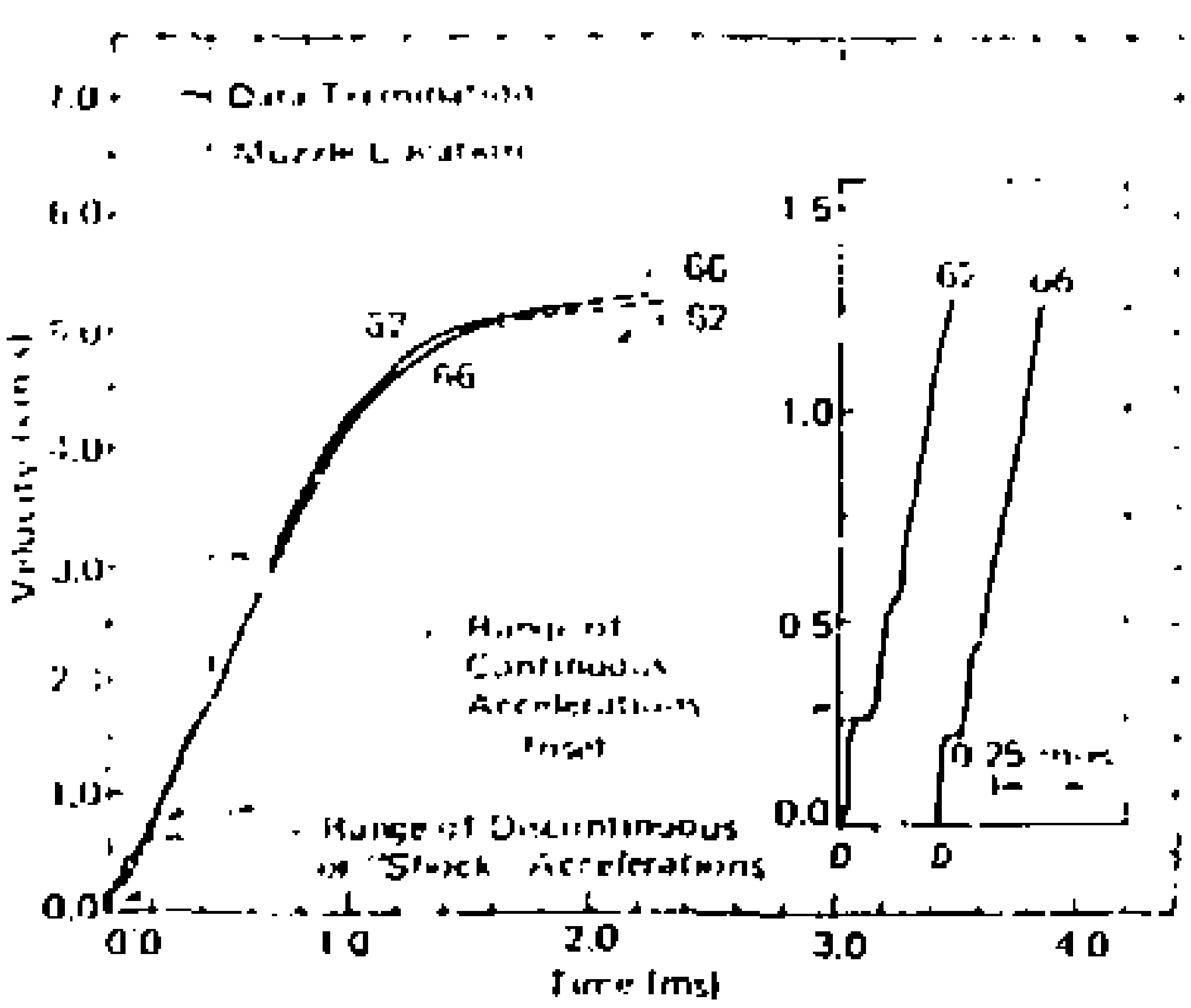


Figure 1. Velocity time histories showing experimental reproducibility

RESEARCH, DEVELOPMENT, AND EVALUATION TESTING

Item 2. *Ultrasonic Measurement System*

An ultrasonic system has been developed at Sandia which measures the velocity and attenuation of an acoustic wave as it travels through a material. The frequency range of the wave may be varied from 0.3 to 5.0 MHz and the temperature of the sample may be varied from -25° to 125°C. This system has proven particularly useful in obtaining low amplitude, high-strain-rate mechanical characterizations of two classes of materials: (1) those that are viscoelastic in nature and (2) heterogeneous materials whose internal geometry disperses waves as they propagate through the material. For the first class, the system is used in a "direct transmission" configuration to obtain velocity and attenuation data at several discrete frequencies over a wide range of temperatures. Using the principle of time-temperature superposition and standard viscoelastic transformations, these data may be used to obtain a "master curve" viscoelastic characterization of the material. These master curves may take several related forms, the most common being velocity versus frequency and relaxation modulus versus time. A typical example of a velocity master curve is shown in Figure 2 for the solid polymer polymethyl methacrylate. For the second class of materials, the system is used in a "water-bath" configuration to obtain dispersion spectra at constant temperature over a range of frequencies. These data map the first pass band of the material and may, depending on the specific material, map the second pass band as well.

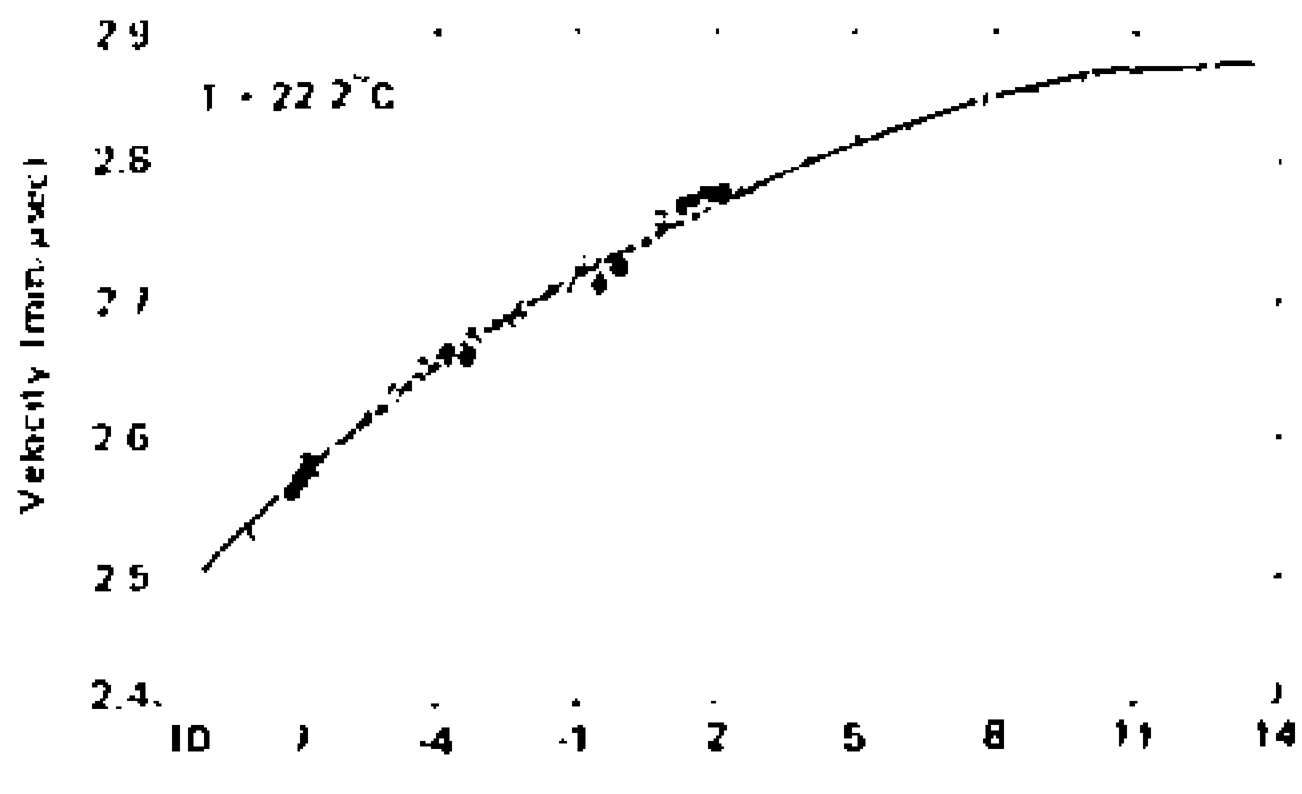


Figure 2. Wave velocity in polymethyl methacrylate as functions of frequency

Item 3. *Triaxial Test Facility*

The computer-controlled triaxial facility is especially adapted for the study of the yield and fracture surfaces of materials with complicated anisotropic constitutive response such as rocks and porous materials (Figure 3). Very rapid response is obtained through a combination of PDP 11/10 computer-activated servo controls and extreme machine stiffness.

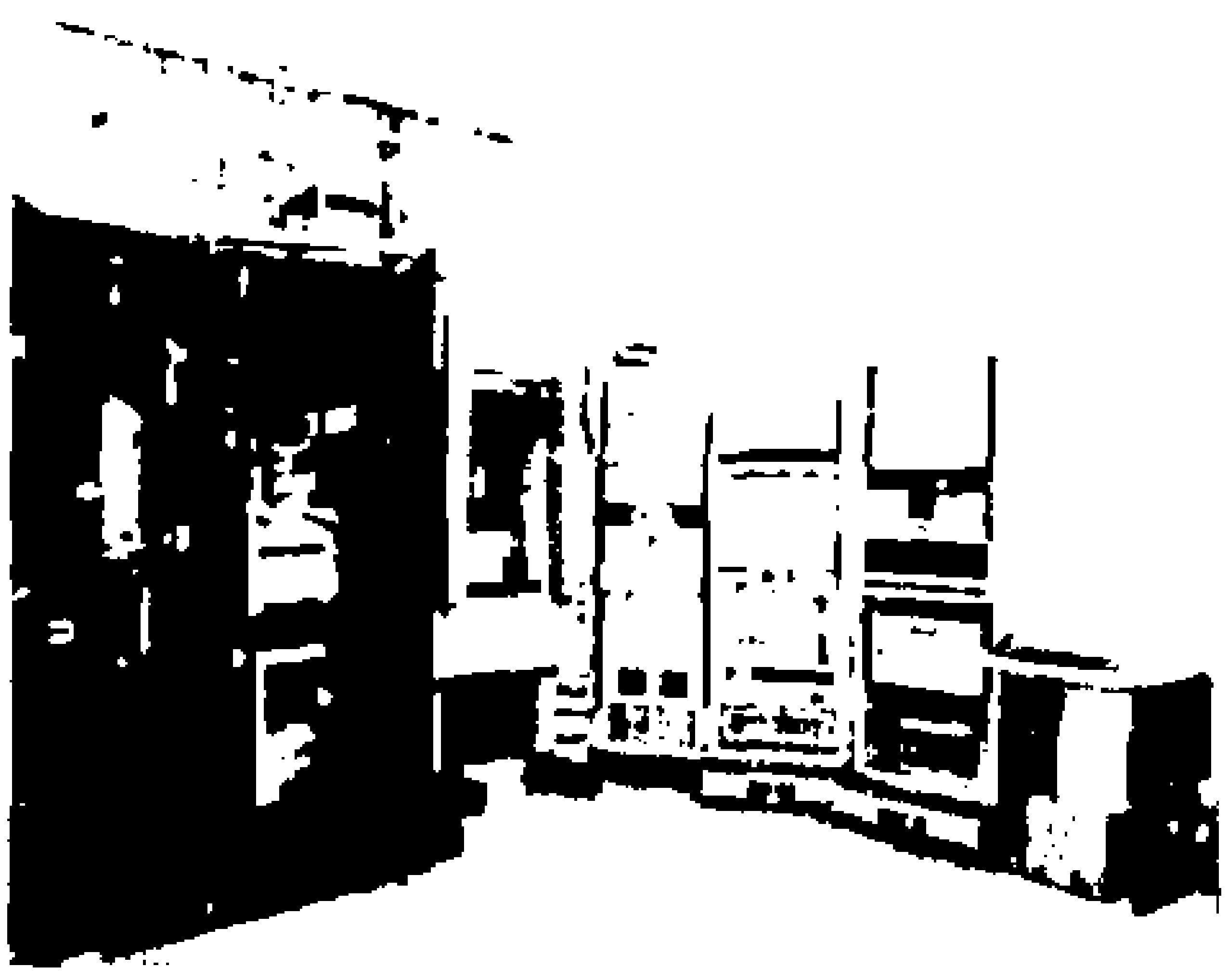


Figure 3. Triaxial test facility

The facility has three pressure vessels (70 MPa, 200 MPa, 1 GPa), each with electrical feedthroughs, an axial loading ram, and a separate pressure-intensifying system. The load frame is rated for 1.78 MN (400 Kip) load, 7.0 x 10^{9} N/m (40 x 10^{6} lb/in.) stiffness, and 2.94 cm/s (1.16 in./s) loading rate.

Two computers are used with the facility for data acquisition and real-time control of test parameters. A PDP 8/1 computer with 64 input channels for analog-to-digital conversion is used when only data acquisition is required. A PDP 11/10 computer is used for real-time control of both pressure and load systems. It has ten channels of analog-to-digital conversion and two high-speed input/output devices.

Both computers output raw test data for transfer over phone lines to a large PDP 10 computer. Data are then reduced with specialized computer codes and plotted on a Tektronic 4010 display terminal. This data management permits data from one test to be reduced and plotted almost simultaneously with the test, so that it can be used on an immediately succeeding test.

Item 4. *High-Temperature Mechanical Properties*

The mechanical properties of graphitic materials at very high temperautres are being determined after the materials have been heated to the desired temperature within a few seconds and at strain rates up to approximately 10 per second. The technique employs self-resistance heating of a tensile or compressive specimen by passing a high electrical current through it in a preprogrammed, feedback-controlled heating cycle and then mechanically loading the specimen monotonically or cyclically through a predetermined stress or deformation history. Load and strain are monitored electronically and optically so that constitutive relations and fundamental deformation mechanisms for arbitrary thermal and mechanical histories can be determined. Transient heating and cyclic loading tests can be used to simulate nuclear reactor transient environments in studying the response of component materials such as cladding, stainless-steel hardware, or pressure-vessel steel.

To prevent thermal conduction along the specimen and into the end grips from producing large temperature gradients in the specimen, the graphite grips are heated separately by RF induction to create "thermal barriers" (Figure 4).

Strain is determined by optically tracking 3 to 5 μm-thick TaC targets sputtered onto specimens that are illuminated by an argon laser. The optical trackers view through narrow-band interference filters to block specimen incandescence. The technique has general applicability for studying the thermomechanical behavior of any conducting material subjected to particular thermal and deformation histories, including cyclic loading, thermal ratcheting, and creep. Graphite sublimation temperatures can be reached in a few seconds under controlled conditions.

Figure 4. High temperature mechanical properties test machine

RESEARCH, DEVELOPMENT, AND EVALUATION TESTING

Nondestructive Testing

Nondestructive testing (NDT) methods are used for locating defects and for quality-control purposes, with emphasis given to techniques for characterizing materials and assessing structural integrity. Acoustic emission, neutron radiography, and laser holometry techniques have been developed while the usefulness of older NDT methods such as radiography and ultrasonics has been extended by image enhancement and automated data acquisition and analysis.

Radiation Test Methods

Information on the uniformity of material properties and the location of subsurface defects is provided to materials, component, and structural groups. Radiation test methods are used to interrogate the internal structures of test items. Special techniques such as microradiography, autoradiography, laminography, and infrared microscopic scans are used. (Item 1)*

Current Techniques

- X radiography (5 kV to 10 MV)
- Isotope gamma radiography (^{60}Co, ^{192}Ir)
- Neutron radiography (pulsed research reactor)
- Radiation gaging (density x thickness -- 10 to 300 kV)
- X-ray Vidicon (fluoroscopy)
- Flash radiography (100 to 600 kV)
- Differential x-ray diffractometry
- Infrared thermography (micro and macro)
- Liquid crystals

Acoustical Test Methods

Ultrasonic, eddy current, and acoustic emission techniques are available to detect flaws and material-property variations. Both manual and computerized data acquisition modes are available to allow complete data analysis. (Items 2,3)

Current Techniques

- Commercial standard and high-energy ultrasonic testing systems interfaced with an interactive data-analysis minicomputer system.
- Commercial and special eddy-current test systems interfaced with minicomputer system
- Multiple-channel triangulation acoustic emission system

*See Highlights below.

Optical Test Methods

Sensitive test methods are used to measure variations in material properties and stress concentrations. Holographic interferometry is used to detect small flaws within the thickness of a material which perturb deformation of the surface of a loaded structure. Small surface perturbations are detected using an automated system analysis technique involving a low-light-level TV camera. A Fourier transform optical system is used to enhance x-radiographs, and neutron radiographs are used for detecting flaws (Items 4,5).

Current Techniques

- Automated quantitative holographic interferometry system using continuous wave and pulsed lasers
- Fourier transform optical system for enhancing radiographs

Other NDT Methods

Special requirements, such as locating discrete surface defects, evaluating weldments, and determining leak rates of hermetically sealed containers, are met by applying NDT methods that do not fall in the classifications cited above. Microscopic surface defects can be imaged using visible and ultraviolet dye penetrants or by spreading magnetic particles on ferromagnetic materials. Leak testing and gas analysis are performed using both commercial and specially designed equipment. Precision leak testing to 10^{-12} cc/s requirements is done using a krypton-85 radioactive gas system. Measurements made with NDT techniques are converted into quantitative form using image-enhancement techniques and digitization methods. Three PDP-11 minicomputers with common interfaces and magnetic tape recording modes have been coupled with such diverse NDT methods as ultrasonics, radiation gaging, eddy current, acoustic emission, and holometry. (Item 6)

RESEARCH, DEVELOPMENT, AND EVALUATION TESTING

• • • • • • *HIGHLIGHTS* • • • • • •

Item 1. *Neutron Radiography*

Neutron radiography has proven to be a valuable NDT method for examining certain classes of materials such as plastics, explosives, and composites. Two types of facilities have been developed to serve the needs of the materials, component, and system groups. One type uses thermalized neutrons from existing research reactors such as the Annular Core Pulsed Reactor, while the other uses a small californium-252 radioisotope which continuously emits large numbers of neutrons and has a half-life of 2-1/2 years. Both types have permitted state-of-the-art resolutions on radiographs of a variety of componentry and have helped to solve design and processing problems undetectable with conventional x-radiography. Neutron radiography has the ability to detect the oil level in an inertial switch. Other applications include the detection of hydrogen embrittlement, density of explosive loadings, and the radiographic imaging of gases such as hydrogen and helium-3.

Item 2. *Acoustic Emission Capabilities in Nondestructive Testing*

Equipment has been developed for locating flaws in small test items by triangulation, which is performed with an 8-channel system that uses a PDP-11 minicomputer for real-time data acquisition, display, and frequency analysis.

Acoustic emission has also been used for studies to determine the switching mode of amorphous semiconductors, for evaluation of rocket-vehicle damage during static qualifying tests, and for pressure-vessel proof tests for safety purposes.

Item 3. *Nondestructive Testing Data-Acquisition, Analysis, and Display Systems*

General-purpose data-acquisition systems based upon PDP-11 minicomputers are used with precision modular fixturing for evaluating test shapes. Test methods include ultrasonic pulse echo, ultrasonic velocity, ultrasonic attenuation, eddy current (surface and through transmission), radiation gaging, acoustic emission, and holographic interferometry. Software exists for such analyses as determining the best position in which to machine a part from a billet, contouring of data, and statistical analysis of data.

Item 4. *Automated Holometry*

Surface deformations are displayed by holographic interferometry, with recorded fringes automated and digitized through interactive controls. Strain calculations can be made rapidly and accurately. The automated system requires the use of a low-light-level camera, a minicomputer, a CRT display, and extensive computer programming. Deformations of simple shapes can be calculated using the minicomputer while more involved calculations are performed on a CDC 6600, since the fringe locations are recorded on IBM-compatible magnetic tape.

Item 5. *Infrared Techniques*

Infrared scanning is applied to both micro- and macro-sized test objects to map thermal contours and to locate discrete defects that reduce component life. The technique is used to scan large objects such as full scale flight vehicles and small objects such as hybrid circuit devices. Automated data-acquisition processes and analytic methods have been developed to allow convenient and meaningful analyses. Unwanted concentrations of heat are located using an infrared microscope and automated scanning table to evaluate heat-sink efficiencies in a hybrid circuit element. Scaled contour plots showing iso-temperature lines are produced on a minicomputer test system that controls power to the hybrid scanning process, and finally calculates and displays the contour lines. Similar operations can be performed on macro-sized objects using a large-scale infrared scanning camera.

Item 6. *Krypton-85 Leak Detection in Sealed Components*

A leak detector using a diluted radioactive gas (1 to 2 percent ^{85}Kr and nitrogen) measures extremely small leaks (to 10^{-13} cc/s) in hermetically sealed components such as transistors. Components to be tested are placed in a pressure tank which is then sealed, evacuated, and pressurized with diluted ^{85}Kr gas. The radioactive gas diffuses into any existing leaks in the components. After a prescribed "soaking" period, the diluted gas is pumped out of the tank and stored for reuse. Components with leaks retain some radioactive atoms, which emit gamma radiation. Components are inspected with a suitable radiation counter, which indicates leak rates as a function of measured radiation.

FIELD TESTING

Test facilities are maintained in areas appropriate for the kinds of testing to be conducted. The Tonopah Test Range in central Nevada is used for flight and trajectory studies, rocket static tests, hard and soft-target airdrops of weapon systems, and high-altitude rocket and reentry-body studies. The Nevada Test Site in southern Nevada is used by this laboratory primarily for investigating the effects of nuclear detonations on materials, structures, components, and complete weapon systems. Radiation diagnostics, seismic, and ground-motion studies are also conducted. *Many nonnuclear tests requiring a controlled environment are conducted at both sites.* The Kauai Test Facility on Kauai, Hawaii, uses the Pacific Missile Range and its rocket-launching capability for high-altitude scientific research and reentry-vehicle studies. In addition to fixed-base testing, field-test operations are conducted at other locations around the world because of special environment demands. The testing technologies required to support these worldwide test operations have been translated into a substantial inventory of test support equipment, the nuclei of which are mobile data-acquisition systems consisting primarily of airborne telemetry systems and transportable recording vans capable of recording large amounts of high-frequency data and processing it for analysis.

Tonopah Test Range

This range is operated by Sandia for development and operational tests and evaluations of weapon systems. When not required for ERDA tests, the range is available on a reimbursable basis to other government agencies and defense contractors.

Situated along a series of dry lake beds between two mountain ranges in central Nevada, the range occupies about 625 square miles of controlled area ideally suited for a variety of field-test operations. The range features controlled airspace, physical remoteness, a relatively quiet radio-frequency environment, an atmosphere of low optical reflectivity, and operational versatility.

Facilities

To cope with diversified testing activities, Tonopah Test Range has acquired a large variety of complete facilities, both fixed and mobile. As testing requirements change, facilities are updated and modified to meet new situations. (Items 1-5)*

Current Facilities

- Rocket and missile launch sites
- Guns for acceleration testing
- Precision tracking systems
- Optical data acquisition
- Electronic data acquisition
- Meteorological information
- Data processing
- Photographic services
- Target areas
- Landing field for aircraft
- Recovery equipment

*See Highlights below.

HIGHLIGHTS

Item 1. *Rocket and Missile Launching Area*

The Tonopah Test Range (TTR) has complete facilities for handling, storing, assembling, firing and recovering rockets whose aeroballistic performance meets conditions prescribed for range safety. The four launchers available are capable of handling the Honest John, Nike, Strypi and Nike-Tomahawk classes of rockets.

Two blockhouses containing monitoring, checkout, and firing equipment are complemented by remotely located telemetry and precision electronic and optical tracking systems. In addition, a large variety of sequential photographic instrumentation is available to permanently record rocket behavior during certain portions of the trajectory.

Support buildings in the general vicinity of the launchers include three assembly buildings providing secure working areas for test units containing explosives. The explosive working areas conform to all safety standards and include a continuous static monitoring system with automatic alarms. One building is equipped with washdown and containment equipment for use in the event of hazardous material dispersion.

Fourteen bunkers for storage of explosives vary in capacity from 22.7 kilograms (50 lb) to a maximum of 22,680 kilograms (50,000 lb). Approved equipment for transporting and handling explosive and hazardous material is available. Personnel are specially trained in handling such materials.

High-performance/high-altitude (600,000 feet) rockets supporting scientific research in solar-flare and stellar x-ray activity have been launched and recovered. In addition, a high-performance (12,000 ft/s), low altitude (20,000 ft msl) capability has permitted development of the Sandia-designed TATER rocket (12,000 ft/s at apogee) to carry test units associated with reentry-body studies.

Item 2. *Gun Test Facility*

This test facility, consisting of two 155-mm and two 8-inch guns, provides a flexible, low-cost method of conducting acceleration (21,000 x gravity axial) tests of unit and instrumentation hardware. The guns have firing elevation ranges of 0 to 90 degrees. Miniature radio-frequency telemetry systems have been developed that can operate and survive within a projectile during accelerations of up to 21,000 ft/s^2, which corresponds to muzzle velocities in excess of 3000 ft/s. Typically, 155-mm and 8-inch shells are fired at elevation angles of 86 degrees to altitudes in excess of 70,000 ft, at which point a parachute system is deployed to provide soft recovery for test items within the projectile.

Item 3. *Precision Tracking Systems*

Two types of precision tracking systems (radar and Contraves cinetheodolites) are used to acquire position, velocity, acceleration, attitude, and limited event data. The radar network consists of two 1-megawatt, 5400 to 5900 MHz, and two 250-kilowatt, 8500 to 9600 MHz, precision tracking radars. These systems collect trajectory position data for approximately 150 miles along the flight path of test vehicles and provide operational data in real time for range use. Six fixed and three mobile Contraves cinetheodolites form a network to obtain metric photo data. Test-unit elevation and azimuth information is recorded on 35-mm film.

Item 4. *Data Acquisition*

Optical:

Sequential engineering photographic records are obtained by two tracking telescopes designed and built by Sandia. The Newtonian-type telescopes, with prime focal lengths of 298.5 cm, are pivotally supported in azimuth mounts so the telescopes can track in elevation and azimuth. Four of the systems are mobile and can be moved to optimum range locations to improve data quality. The long-focal-length lenses are temperature-corrected and are kept in focus with radar data to provide excellent images of targets at extreme distances.

A small, highly mobile tracking mount, capable of much higher tracking rates, carries a 304.8-mm Newtonian telescope with a focal length of 152 cm. It also features special photographic instrumentation for high-speed impact data. Both the azimuth-elevation tracking telescopes and the impact telescope are kept in focus with radar data and are temperature-corrected.

Electronic:

Three mobile and three fixed radio-frequency (225 to 260 MHz, 1435 to 1540 MHz, 2200 to 2300 MHz) telemetry stations are equipped with various combinations of receiving, display, and recording equipment, with magnetic tape recording responses up to 1.5 MHz. Special telemetry requirements such as operation at frequencies other than those normally assigned to the range can also be accommodated.

FIELD TESTING

Item 5. *Target Areas*

Range topography and soil composition offer range users the choice of several targets with a variety of earth conditions. The string of dry lake beds through the center of the range is the target series used when hard-packed, clay-base soil is desired. Other locations provide sand and sand-clay mixtures, as well as gravel, rocky, or solid-rock impact areas.

There is a circular 1-foot-thick 4000-psi concrete target at the south end of the main lake, surrounded by numerous data-gathering stations designed to provide detailed impact data.

Air-dropped test units vary in shape from twice cigarette-pack size (air-deliverable electronic countermeasures) to ballistic shapes exceeding 12 feet in length. Test-unit velocity has ranged from 2000 to 100 ft/s for parachute-retarded vehicles. Delivery aircraft vary from low-performance propeller-driven types to B-52 jet-bombers with release altitudes between 50 and 55,000 feet above ground level.

FIELD TESTING

Nevada Test Site

The Nevada Test Site was established so that nuclear-weapon development and effects experiments could be conducted in a controlled manner to ensure the safety of both test participants and the public. Sandia has complete access to all its resources and services within established rules, regulations, and practices. The test site is located in southern Nevada in a basin-and-range topographic environment. The operational test areas of the site are located approximately 150 kilometers northwest of Las Vegas, the closest contact with industry, public transportation, and commerce.

Facilities

Administrative headquarters for the overall test site are at Mercury, Nevada, where living quarters, utilities, recreation facilities, warehouse facilities, and administrative offices are located. Sandia maintains permanent facilities in both Mercury and in the forward testing areas to support its field-test operations at the Nevada Test Site. In addition to the fleet of data-acquisition trailers, these facilities include electronics maintenance shops, parts storage, photographic labs, and a complete machine shop. Sandia also maintains facilities in the testing areas where experiments are assembled and checked out. Some assembly areas contain heavy-duty assembly equipment and are supported by a portable machine shop. (Items 1-5)*

*See Highlights below

Current Activities

- Nuclear
  - Radiation diagnostics
  - Ground motion
  - Effects measurements
  - Transducer development
  - Test bed design
  - High-fluence test technique development
  - Arming and firing
  - Containment studies
  - Containment hardware development
- Nonnuclear
  - Soil pore pressure measurements
  - Structural response measurements
  - Ground motion
  - Hydrofracturing

• • • • • • *HIGHLIGHTS* • • • • • •

Item 1. *Data Acquisition Systems*

In support of underground test programs investigating nuclear effects, Sandia has established a capability to acquire large amounts of high-speed data on a one-time basis at the Nevada Test Site. This capability consists of approximately 500 channels with 1-kHz response and 1000 channels of FM-FM multiplexed magnetic tape recording with frequency response from 20 to 400 kHz. Approximately 300 oscilloscopes are also available. This recording capability is completely mobile in a fleet of approximately two dozen trailers (*Figure 1 and Table 1*). Each recording trailer has its own diesel-powered generators, self-contained environmental systems, programmable control and playback system, and remote operation capability. Fixed-based installations are also used with equivalent recording and playback capabilities.

Sandia is updating its mobile recording capability from analog to digital. The new digital system will be completely programmable by varying the frequency response of the recording channel as a function of time relative to the start of a recording period. Each trailer will be set up to handle from 250 to 500 channels of information with frequency response to approximately 100 MHz. Duration of recording is highly dependent on frequency response.

A mobile downhole TV system involves lowering a 6-inch video camera in a wet or dry hole to depths of 6000 feet in temperatures up to 140°F. Pan and tilt options as well as directional readouts are available. A 4-inch camera is available for depths to 2500 feet.

FIELD TESTING

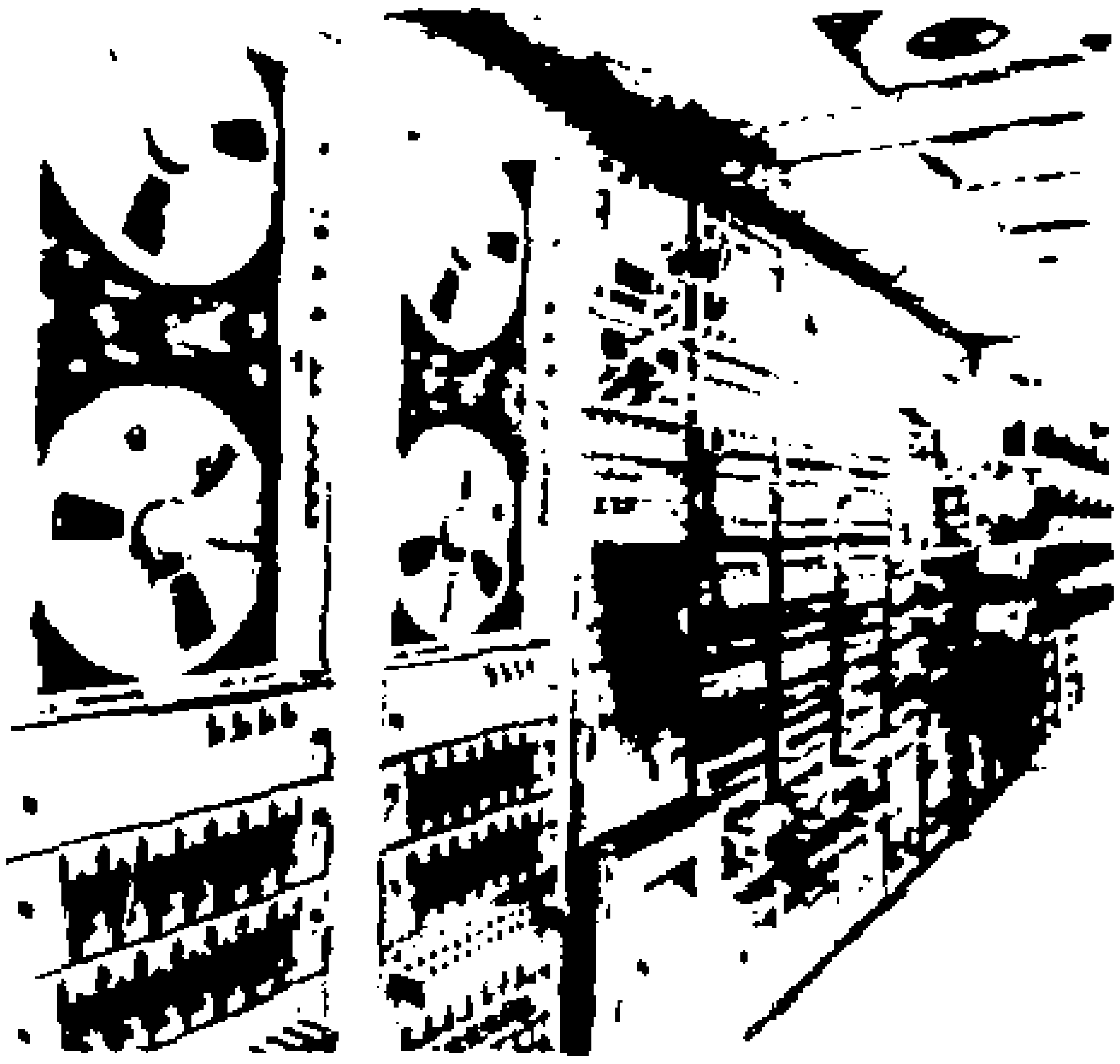


Figure 1. Typical multichannel instrumentation in mobile station for recording of underground test data

TABLE I

Trailer Number	Multiplex Channels Frequency Response (kHz) 1	20	50	500	Oscilloscope Channels Frequency Response (MHz) ≤100	≥100
B-20		72		12	16	
B-21		7		14	18	5
B-22		11	58	12	16	
B-23	100	91				
B-25		91		10	16	
B-38		11	58	12		4
B-51						16
B-61		42		12	15	25
B-62		42		12	27	13
B-63		42		12	20	14
B-69			63	12	21	7
B-72		11	63	12	14	14
T-31		91			17	
T-32		91		12	15	
B-74	96				16	
B-3	96					
B-4	50					
B-17	172					
T-27				10	16	
Totals	514	602	242	142	227	98

Item 2. *Radiation Diagnostics*

Radiation-output diagnostic measurements are made to define the free-field environment of x-rays, gamma rays and neutrons on nuclear-weapon effects tests. Activities range from the inception of new measurement techniques, through the design, calibration, fielding, data analysis, and reporting of results. Laboratory equipment includes x-ray generators, both direct current and pulsed; counting and recording apparatus and multichannel analyzers; oscilloscopes, power supplies, and optical spectrophotometers.

Item 3. *Effects Measurements*

Measuring the response of a material, a component or a whole structure during exposure to a nuclear-detonation environment is a prime activity. Typical measurements include temperature, pressure, hydrodynamic shock stress, structural strain, velocity, and acceleration of materials and structures. Special techniques were developed to make measurements in an intense radiation environment. These included modification of the quartz shock-pressure gage and development of a linear-velocity transducer to measure the momentum imparted to a material by radiation.

Item 4. *Ground-Motion Measurements*

Three components of ground surface motion are routinely measured on selected underground nuclear detonations. The measurements are made from surface ground zero out to distances several times the burial depth of the explosion. Ground shock pressure has been measured with ytterbium and lithium niobate gages from about 3 kilobars to less than 100 bars. Ground motions with peak accelerations between 10^4 and 10^{-2} x gravity and peak velocities between 10^2 and 10^{-4} m/s have been measured.

Item 5. *Test Facility Design*

A nuclear-effects test requires the design and fabrication of an underground facility that must conform to many exacting scientific requirements as well as to severe geo-political regulations requiring complete containment of the environment resulting from the nuclear detonation. Stemming and containment features and experiment-protection systems are designed by using information obtained from ground-motion and radiation diagnostics from previous tests as inputs to one- and two-dimensional hydrodynamic computer codes. Criteria for the design and construction of the test bed are established from the analysis.

Kauai Test Facility

Sandia maintains a permanent test facility at the Pacific Missile Range installation on Kauai, Hawaii, with resources for complete assembly, checkout, and launching of sounding rockets, plus a capability for receiving and playing back telemetry data. Both the Pacific Missile Range and the nearby National Aeronautics and Space Administration installation have facilities for tracking rockets and recording data. The Pacific Range also provides aircraft and ships to recover payloads after some tests.

Test facilities exist for developing and testing high-altitude rocket systems used to study reentry-vehicle characteristics and atmospheric effects caused by nuclear reactions and radiation emissions from stars.

Mobile Testing

Limited numbers of tests that must be conducted at specific global locations are supported by mobile test facilities. Test series of this type have included undersea recovery of a nuclear reactor, Arctic icepack depth measurements, penetration studies using recoilless rifles, rocket launch checkout and undersea recovery, and remote-site rocket launches.

Facilities

The mobile facilities are self-contained and include power, communications, and instrumentation. Instrumentation includes measurement techniques such as geophonics and hydrophonics, seismology, and meteorology equipment, and analytical tools for analyzing thermal and chemical properties. Auxiliary equipment exists to transport personnel and equipment and to operate in severe environments. (Items 1-5)*

*See Highlights below.

Current Facilities

- Data acquisition systems
- Photographic equipment
- Data-display systems
- Data-evaluation systems
- Hydrophones
- Surveying equipment
- Aircraft position-control equipment
- Communication systems
- Aircraft
- All-terrain vehicles
- Drilling equipment

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Item 1. *Ice-Penetration Studies*

Measurements have been made of the mechanism of penetration into most types of ice by free-falling test vehicles. Operating conditions have included fresh-water ice, annual ice, and multiyear pack ice in the Bering Straits, Beaufort Sea, Baffin Bay, the ice cap north of Greenland, and frozen lakes from sea level to 7000 feet MSL. Aircraft are used to deliver the test vehicles. Telemetry and real-time data analysis is performed on the ground as well as in the drop aircraft. Impact control is provided by an in-house optical system that can be located anywhere that a man can be stationed.

FIELD TESTING

Item 2. *Terradynamic Studies*

The 8- and 12-inch recoilless rifle systems, and closed-breech compressed-air and gun systems, have been fielded in environments from swamps to Rocky Mountain stone for test-vehicle implant measurements. Typically these operations include high-speed photometric measurements of velocity and shock-wave phenomena. Telemetry includes in-barrel and subsurface data to obtain a complete acceleration profile. Prelaunch calibration and near-real-time computer analysis of the data is provided for both time- and frequency-shared telemetry systems. Test-vehicle velocities have ranged from 200 feet per second to Mach 3. Vehicles are recovered after test and the ground is restored to its original condition. Administrative and logistics services provided by the testing organizations include movement, storage, and handling of explosives, real-estate rentals, surveillance radars, geological logging, and life-support systems.

Item 3. *Undersea Nuclear Power Generator Recovery*

A polar-orbit payload launched southward from Vandenberg Air Force Base veered off course shortly after launch and was destroyed. The payload contained a nuclear isotopic power source that had to be located and recovered. Normal naval search systems failed to locate the debris in the Point Conception area. Within 2 weeks, Sandia assembled a hydrophone system with a plotting board similar to that available in a tracking radar station, put it aboard a chartered vessel, controlled a chartered research submarine bottom search, and located the generator for a successful and safe recovery.

Item 4. *Rocket Test Support*

Test support includes airborne and shipboard recording of telemetry, prelaunch calibration of instrumentation systems, near-real-time data analysis, underwater hydrophone measurements, and deep-sea recovery. These types of tests have been performed from the Atlantic to the Caribbean, the Gulf of Mexico, the western US shoreline (San Diego to Vancouver), and to the Pacific to Johnston Atoll.

Item 5. *Major Rocket Systems*

The mobile remote range facilities provide specialized prelaunch calibration and data analysis of payloads for major missile systems, some associated with weapons and others with research in geophysical phenomena. Launches have been made from such remote areas as the southern tip of Brazil and above the Arctic Circle. National range facilities are used whenever possible to supplement Sandia's specialized instrumentation requirements. High-pressure and vacuum-system technologies have been important parts of the calibration systems. Complex time- and frequency-shared RF telemetry systems are involved in most missile tests. The typical telemetry system checkout facility, including computer system, is packaged in a 10 x 40 foot trailer and is valued at about $800,000. When necessary, the trailer is equipped with air-to-ground and ship-to-shore communications for coordination and control of associated aircraft and ship instrumentation.