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Summary of

Sandia Laboratories Technical Capabilities

Sandia Laboratories

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SUMMARY OF

SANDIA LABORATORIES TECHNICAL CAPABILITIES

ABSTRACT

The technical capabilities of Sandia Laboratories are detailed in a series of companion reports. In this summary the use of the capabilities in technical programs is outlined and the capabilities are summarized.

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 18 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
(SAND77-0651)

Aerosciences	SAND74-0075	Instrumentation and Data Systems	SAND74-0083
Applied Mathematics	SAND74-0079	Materials and Processes	SAND77-0002
Biosciences	SAND74-0076	Measurement Standards	SAND74-0077
Computation Systems	SAND77-0767	Physical Sciences	SAND74-0074
Design Definition and Fabrication	SAND76-0413	Quality Assurance	SAND77-0650
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Explosives, Electrochemistry, and Electromechanisms	SAND74-0081	Auxiliary Capabilities: Environmental Health; Information Sciences	SAND74-0082

Compilation of
Sandia Laboratories Technical Capabilities
(SAND74-0092)

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INTRODUCTION

In this summary the technical capabilities of Sandia Laboratories and their application to national security, energy, and other federal programs are briefly described. These capabilities are the basic scientific and engineering disciplines and technologies currently in use at these Laboratories. They are the tool used to define and solve scientific and engineering problems and to conduct research, development, testing, and evaluation of advanced systems.

The reason for describing these technical capabilities is so that they can be more efficiently brought to bear upon two major areas of national concern - national security and energy. The reports associated with this summary:

- Provide an inventory of resources that will allow overall program planning in relation to national problems.
- Furnish information needed by Sandia management to balance project requirements with technical capabilities.
- Supply an additional basis for communication among federal agencies, laboratories, universities, industries, and the Laboratories' own staff.
- Provide source material for reports, proposals, presentations, and recruiting purposes.

A breakdown of the managerial and technical capabilities is given on the following page.

OPERATIONAL STRUCTURE

The technical capabilities of these Laboratories are located in functional organizations dedicated to individual disciplines and technologies. Responsibility for individual projects is assigned to project organizations which rely upon the functional organizations for support. The project/functional relationship is advantageous because responsibility for a project is assigned to a single manager and his staff, and continuity of control over the assigned system is assured. This control is necessary to assure the integration of complex designs having stringent requirements for performance, reliability, safety, and longevity. The relationship also permits detailed technical direction to be concentrated at the level where primary technical competence exists.

The use of the most recent scientific and engineering advances on the various projects is assured through the interaction of the technical staff with the general technical community. This interaction includes publication in technical journals, participation in national and international conferences, and personal exchanges of information with peers. The continuing challenge of interesting and important problems and the resulting long-term continuity of personnel provides stability of the essential technical staff.

The technical staff is utilized by the project managers in the major areas of national security, energy, and work for other federal programs.

SYSTEM ENGINEERING AND MANAGEMENT

Technical Management
Fiscal Controls
Program Direction

TECHNICAL CAPABILITIES

SCIENCE AND ENGINEERING

PHYSICAL SCIENCES SAND74-0074*
- Physics of Surfaces and Near-Surface Layers
- Physics of Solids
- Solid Dynamics and Shock Wave Phenomena
- Interaction of Radiation with Matter
- Laser Physics
- Relativistic Electron Beam Research
- Research Reactors

APPLIED MATHEMATICS SAND74-0079
- Development of Computer Codes
- *Discrete Mathematics*
- Mathematical Physics
- Theoretical Mathematics
- Statistical Analysis

EXPLOSIVES AND PYROTECHNICS SAND74-0081
- Detonation Physics
- Chemistry of Explosives
- Chemistry of Pyrotechnics

ELECTROCHEMISTRY SAND74-0081
- Electrochemical Power Sources
- Physical Chemistry
- Thermal Analysis

ELECTRONICS SAND74-0086
- Active Semiconductors
- *Hybrid Microcircuits*
- Vacuum Tubes
- Pulsed High Energy Technology

EARTH SCIENCES SAND74-0085
- Numerical Methods
- Terradynamics
- Underground Physics
- Drilling, Magma, and *Diagnostic Technologies*
- Rock Mechanics

ELECTROMECHANISMS SAND74-0081
- Environment Sensing
- Guidance and Control
- Switching Technology
- Timing Technology
- Analysis

MATERIALS AND PROCESSES SAND77-0002
- Metallurgy
- Composites
- Surface Characterization and Film Deposition
- *Polymers*
- Ceramics and Glasses
- High-Temperature Characterization of Materials
- *Laboratory Analysis and Chemical Technology*

BIOSCIENCES SAND74-0076
- Environmental Biology
- Applied Biology
- Analytical Biology

AEROSCIENCES SAND74-0075
- Aeroballistics
- Aerodynamics
- Atomic and Fluid Physics
- Aerothermodynamics
- Aerophysics
- Atmospheric Environments
- Fluid Dynamics
- Aeromechanical Design

SAFETY ASSURANCE SAND74-0090
- Safety Assessment
- Safety Assurance
- System Safety

RELIABILITY ASSURANCE SAND74-0090
- Reliability Assessment
- Statistical Design and Analysis
- Human Factors
- Quality Control

QUALITY ASSURANCE SAND77-0652
- Program Implementation
- Test Program Development
- Product Acceptance and Production Control
- New and Field Material Surveillance
- Data Base Management

ANALYSIS AND TESTING

SYSTEMS ANALYSIS SAND74-0088
- Problem Definition and Assessment
- Concept Formulation
- System Evaluation
- Concept Optimization

ENGINEERING ANALYSIS SAND74-0087
- Structural Mechanics
- *Stress Wave Analysis*
- Explosive Technology
- Heat Transfer
- Aerospace Engineering
- Mechanism Analysis
- Environment Analysis
- *Controls Engineering*
- Electrical Engineering
- Nuclear Engineering
- Reactor Safety Analysis

TESTING SAND74-0088
- Environmental Simulation
  - Mechanical Loading
  - Radiation Loading
- Development and Evaluation
  - Aerosciences
  - Material Response
  - Nondestructive Testing
  - *Solar Systems*
- Field Testing
  - Tonopah Test Range
  - Nevada Test Site
  - Kauai Test Facility
  - Mobile Facilities
  - *Remote Ranges*

INSTRUMENTATION SAND74-0083
- Data Acquisition
  - Transducers
  - Communications
  - Optical Recording
  - Mobile and Transportable Instrumentation
- Special Instrumentation
  - Meteorological
  - *Photometric*
  - Quality Assurance
  - Radiation Analysis
  - In Situ Measurements and Control

DATA REDUCTION SYSTEMS SAND74-0083
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- Optical

SUPPORT FUNCTIONS

FABRICATION SAND76-0413
- Metals
- *Glasses and Ceramics*
- Composites and Plastics
- Electrical Components
- Heat Treating and Finishing

INFORMATION SCIENCE SAND74-0082
- Information Management
- Information Dissemination
- Reference and Translation

COMPUTATION SYSTEMS SAND77-0767
- System Planning, Development, and Support
- *Central Computing*
- Remote Computing
- Interactive Graphics
- Computer-Based Special-Purpose Systems

DESIGN DEFINITION SAND76-0413
- Design Drawings and Specifications
- Computer-Aided Design
- Information Control Systems

MEASUREMENT STANDARDS SAND74-0077
- ERDA Standardization Program Management
- *Direct-Current Electrical Quantities*
- Microwave Quantities
- Radiation
- Mechanical
- Environmental

ENVIRONMENTAL HEALTH SAND74-0082
- Hazard Control
- Radiation Dosimetry
- Radiation Counting
- Effluent Documentation

APPLICATIONS OF CAPABILITIES

NATIONAL SECURITY PROJECTS

The responsibilities of the Laboratories in national security missions are to develop and maintain the scientific and engineering expertise that will assure viability of the nation's nuclear ordnance; to conduct research that will generate new weapon concepts; to design and develop nuclear ordnance in conjunction with other national laboratories; to verify that the weapon stockpile remains a credible deterrent through continual assessment of safety and reliability; to modify weapons as necessary to meet new requirements; and to develop and apply advanced technologies to the protection of nuclear materials from theft.

It is upon these responsibilities that the technical capabilities are concentrated, as shown in the schematic on the following page. While most national security projects are classified and cannot be discussed here, a few representative examples are described below.

• • • • • • • • • • •

System Integration

The application of Sandia's technical capabilities to problems of system integration led to major advances in the design and development of small reentry vehicles. These advances were in response to a national security problem, which was to find a way to preclude possible exhaustion of the U.S. missile force by ballistic missile defense systems then being developed by potential adversaries.

A solution to the problem involved the deployment of decoys, which the enemy could not discriminate from actual warheads and therefore could not dismiss. Another alternative led to an intensive study of lightweight reentry vehicles, resulting in the development of smaller, lighter warheads containing miniaturized components (Figure 1).

This technology was based upon a number of basic capabilities, including: systems analysis to establish optimal designs; engineering analysis by multidimensional computer programs to determine shock and structural loads; materials studies to determine and apply dynamic properties; physical sciences to determine the response of materials to radiation; electronics and electromechanics for the miniaturization and design of electrical components; and extensive use of testing facilities.

The technology has since been applied to the development of integrated arming, fuzing, and firing systems such as the Navy's Poseidon and Trident missiles. Components developed for these systems include integrating accelerometers, radar fuzes, electromechanical and electronic timers, and thermal batteries.

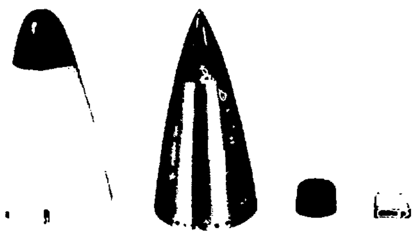
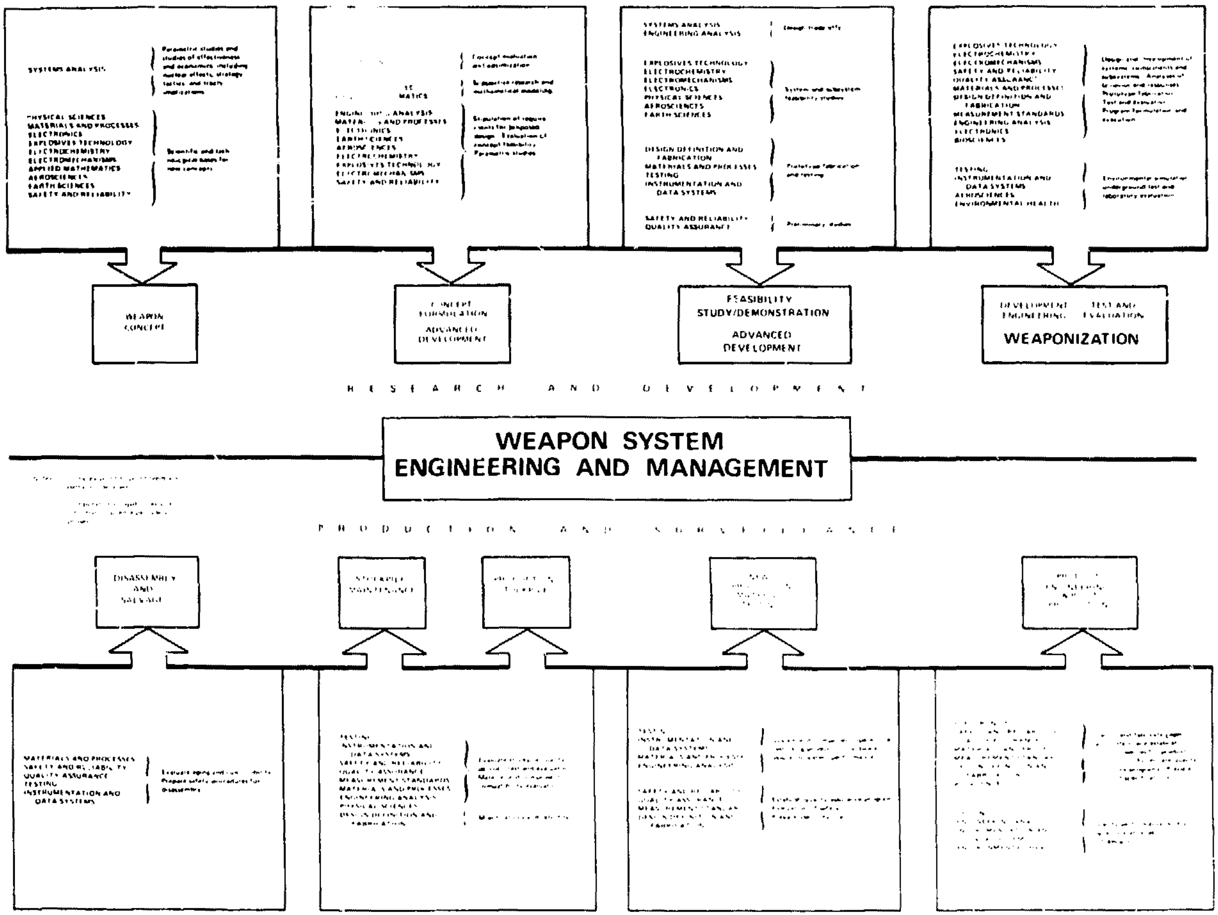


Figure 1. Continuing improvements in miniaturization are illustrated by these periodic reductions in the size of a radar fuzing component.

Nuclear Weapon Security

Sandia pioneered concepts for inhibiting the unauthorized use of nuclear weapons. Security locks containing sophisticated logic have become small enough to be embedded in critical weapon components. Newer technology provides the capability to destroy or disable the weapon. A storage vessel has been designed to contain all the products of an explosion, including fissionable material. Other techniques for disabling a weapon include rendering the radioactive material useless by chemical, physical, or isotopic means (Figure 2).

Use of these techniques has raised confidence levels in the security of nuclear weapons deployed overseas.



EXAMPLES OF CAPABILITIES REQUIRED FOR SOME OF THE ACTIVITIES ASSOCIATED WITH A [illegible]

APPLICATIONS OF CAPABILITIES

Figure 2 Cross section of special nuclear material that has been chemically altered into slag and metallic components, both of which contain uranium, but in dilute, unusable form

Safety: The Weak-Link/Strong-Link Concept

Without safety devices, the electrical system of a nuclear weapon would be vulnerable to fire, deep water, lightning, crushing impacts, or high-velocity projectiles. Design features of weapon electrical systems have been combined to obtain predictably safe responses in such environments. In a special exclusion region of the electrical system, selected "weak links," which are vital to weapon operation, are interrupted by open contacts from "strong links," which are accident-resistant switches that respond only to unique signals (Figure 3). Electrical elements are so combined and sequenced that the weapon system will not operate if premature signals from any source arrive at the exclusion region, because the weak links will always fail before the strong links can do so.

This designed response does not require a detailed understanding of the complex environments encountered in accidents. Use of this concept also eliminates the need for lengthy evaluations of power supplies and wiring outside the exclusion region. Consequently, system safety can be economically verified by relatively simple analyses and tests.

Earth-Penetrating Weapons

Nuclear weapon systems that penetrate deeply into the earth before detonating can be used to create barriers or craters to impede troop advances; to destroy targets that are vulnerable to burial or sensitive to ground shock, and to reduce the spread of radioactive contamination. Such penetrating warheads were made possible because of an extensive terradynamics research and development program carried on by Sandia over the past decade, and because of development of a superior heat treatment that makes a steel alloy highly resistant to fracture (Figure 4). A mobile vertically fired recoilless gun (Figure 5) was used for extensive testing, and instrumentation was developed to withstand resultant high-impact loadings.

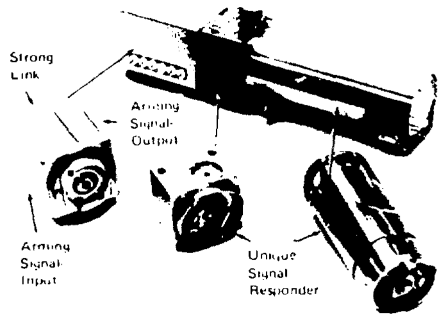


Figure 3. Strong link and unique-signal detector of a weapon safety component.

Figure 4. Unfractured penetrator recovered at a depth of 57 metres.

Penetrators have also been used to measure thicknesses and properties of sea ice (Figure 6), have been designed to measure the surface properties of Mars, have formed the basis for innovative deep-drilling designs and for ways of implanting instruments to locate fossil-fuel deposits, and are being designed to make geotechnical measurements of ocean-bottom sediments for locating offshore drilling platforms.

Figure 5. Recoilless gun used to fire penetrators vertically into soils.

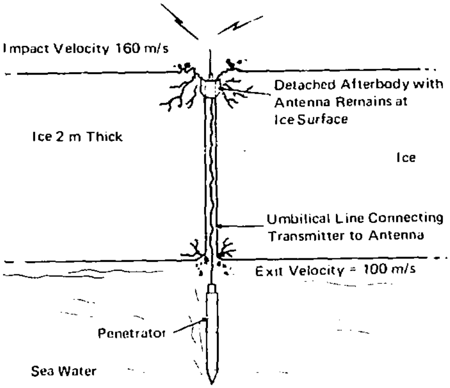


Figure 6. Method by which an instrumented penetrator is used to measure sea ice properties and thickness.

APPLICATIONS OF CAPABILITIES

ENERGY PROJECTS

It is a policy of these Laboratories to apply its capabilities to problems of national concern. Consequently, existing projects aimed at increasing the supply of domestic energy and developing methods of conserving energy resources have been accelerated and additional projects are being undertaken. Representative examples and an outline of the energy programs follow.

* * * * * * * * * * *

Electron-Beam Fusion

The electron-beam fusion program is a study of mechanisms involved in the production of fusion by inertial compression of thermonuclear fuel, and development of the technology for producing the physical conditions necessary for this process. The near-term goal is to provide an in-house capability to study the physics of small-scale thermonuclear explosions. Over a longer period, this capability could lead to a fusion power source or a fissile material breeder. Radiation produced by these explosions can also be used to test the ability of weapon components to function in a nuclear countermeasure environment.

The program involves systematic attempts to scale early results to increasingly higher levels of input power. Recent experiments illustrate satisfactorily symmetrical energy deposition on a spherical target (Figure 7).

Now under construction is one of the world's highest-power electron-beam accelerators, developed expressly for use in fusion studies. The accelerator (Figure 8) will subject a fusion pellet to two 400,000-amp beams for 25 billionths of a second. Total power will be about 2 trillion watts.

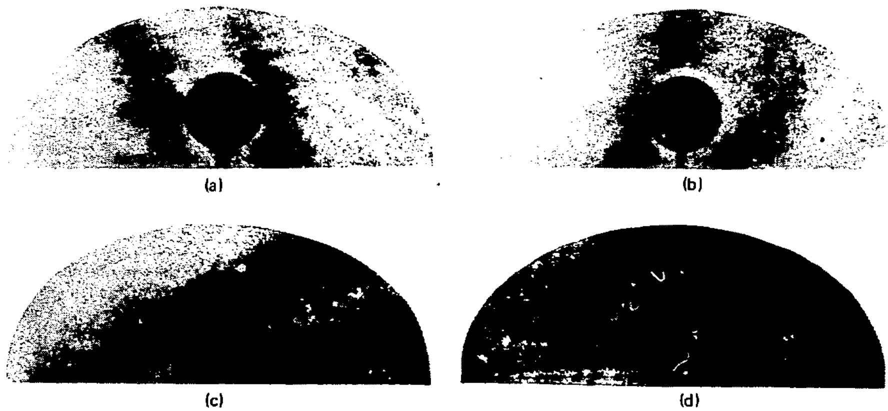


Figure 7. Sequence illustrating how material ablates (concentric outer rings) from surface of spherical target in electron-beam fusion experiment.

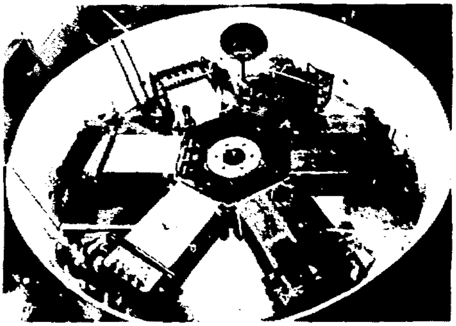


Figure 8. The world's largest electron-beam accelerator under construction. Shown are six voltage multipliers which receive their charge from a large capacitor bank and direct their energy into two diodes that will occupy the space in the center.

Combustion Research

Because of the present heavy dependence upon fossil fuels, combustion research has the potential for making major contributions to our energy future by allowing development of more efficient, less polluting systems. In the past, such research has been hindered by lack of adequate diagnostic techniques. The underlying analytical and experimental capability was first developed to study gas dynamics for the weapon program and was then extended to the study of combustion processes. Activities include the use of high-powered lasers for analyzing combustion processes (Figure 9), the study of turbulent reacting flows, applied research emphasizing automotive propulsion, and advanced coal-burning power cycles and coal processing.

Solar Energy

Sandia Laboratories is the technical manager of the Solar Central Receiver project for ERDA. The goal of this project is the design and construction of a 10-megawatt (electric) pilot plant. As a part of this project, a 5-megawatt (thermal) test facility will be constructed primarily to test and evaluate solar receivers.

Another major project in Sandia's energy effort is the Solar Total Energy Program. This is an energy cascading concept in which solar energy is used to generate electrical power and the normally wasted heat from electrical power generation is used for heating and cooling buildings and for domestic hot water (Figure 10).

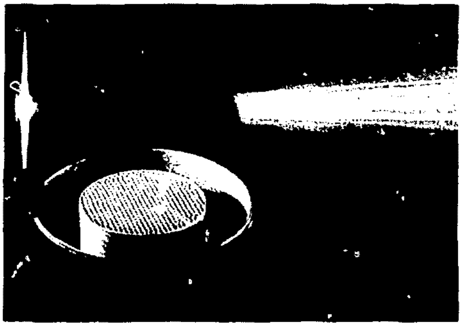


Figure 9. In an experiment involving combustion analysis by lasers, spatial and time-resolved specie concentrations and temperatures of gaseous combustion products are measured using Raman scattering techniques.

Figure 10. Two parabolic line-focusing reflectors, measuring 2.7 x 3.7 metres, of the type to be used in the Solar Total Energy System, are shown mounted for testing and evaluation. In operation, solar radiation is reflected and focused on receiver tubes through which a heat-transfer fluid is pumped.

ENERGY PROGRAMS AT SANDIA LABORATORIES*

SOLAR ENERGY
- Central Receiver
- Solar Total Energy
- Photovoltaics

FOSSIL ENERGY
- Enhanced Gas Extraction
- Offshore Technology
- Coal Gasification
- Synthetic Fuels
- Oil Shale

FUSION ENERGY
- Particle Beam Fusion
- Laser Fusion

FISSION ENERGY
- Fast Reactor and Fuel Cycle Safety
- Light Water Reactor Safety Research
- Waste Management

NUCLEAR MATERIAL SECURITY
- Physical Protection of Nuclear Facilities
- Protection of Nuclear Material in Transit
- Safeguards

ENERGY CONSERVATION
- Combustion Diagnostics
- Energy Storage
- Variable-Displacement Spark-Ignition Engine

GEOTHERMAL ENERGY
- Drilling Technology
- Logging
- Magma Energy

ENVIRONMENT AND SAFETY
- Environmental Policy Analysis
- Transport of Nuclear Materials
- Atmospheric Pollution

BASIC ENERGY SCIENCES
- Material Sciences
- Combustion Research

*These energy programs are described in a report titled "Sandia Laboratories Energy Programs" and is identified by SAND77-0034.

PROGRAMS FOR OTHER FEDERAL AGENCIES

Much of the work done for federal agencies other than the Energy Research and Development Administration is performed for the Department of Defense and is classified. An example is the design and development of satellite-carried nuclear burst detectors. Nondefense work includes studies of the environmental effects of supersonic aircraft on the atmosphere for the Department of Transportation and the development of instrumentation for monitoring fissionable materials for the Arms Control and Disarmament Agency. Other sponsoring organizations include the National Aeronautics and Space Administration, the National Science Foundation, and the National Institutes of Health. An example of work for the Nuclear Regulatory Commission is described below.

* * * * * * * * * * *

Safety and Security Studies

In work related to the nuclear fuel cycle, activities consist of the technical evaluation of systems and components designed to protect against the release of radioactivity. Experiments and system studies are conducted to elucidate the behavior of reactor components and nuclear fuels under accident conditions, and to determine the nature and degree of hazards associated with other segments of the nuclear fuel cycle. Of particular concern are risks attendant upon transportation of fuel materials and radioactive wastes. Here the objective is to safeguard the material from diversion by terrorist groups, and to prevent its dispersal in the event of accident or sabotage. Because of the high toxicity of plutonium and its potential for use in nuclear weapons, its shipment is under very close scrutiny. As part of this investigation, containers used for shipping plutonium are being tested to see how well they withstand severe impact and explosion environments. Figure 11 shows such a container after being driven into any unyielding steel surface at 120 metres per second. In this end-on impact, the outer container was breached, but the inner container remained intact. It was found that other impact conditions are more likely to breach both containers.

Figure 11. Components of a shipping container for plutonium that was driven into a steel surface by a rocket sled.

SUMMARY OF CAPABILITIES

SYSTEM ENGINEERING AND MANAGEMENT

The form of direction provided by Sandia technical management is directly dependent upon the number of technical capabilities required to complete a project. Extensive projects such as weapon programs require essentially all of the capabilities and are directed by a program manager and his staff. Smaller projects, such as research, are centered in a particular discipline and are managed by the technical staff of the organization specializing in that capability.

Individual projects for national security, energy, and other federal programs are directed by the System Engineering and Management staff. Their function is to provide technical direction, control expenditures, and direct the progress of engineering programs. The system staff consists of engineers and scientists of diversified enterests and backgrounds. The system staff defines the objectives of a system and environments in which it must function, and evaluates cost and associated trade-offs needed to attain cost effectiveness.

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TECHNICAL CAPABILITIES

SCIENCE AND ENGINEERING

PHYSICAL SCIENCES

Research in the physical sciences is directed toward understanding basic phenomena, enhancing physical characteristics, and developing predictive capabilities for practical applications. Studies in the physics of solids, surfaces, and thin surface layers are leading to improvements in solid-state devices. Work on the dynamics of stress and shock waves is directed toward generating computer codes to augment or replace costly and time-consuming hardware testing. Investigations into the interaction of radiation with matter are resulting in techniques to ameliorate radiation-induced damage in solid-state components. Research in laser fusion and electron-beam fusion constitutes an essential part of the nation's program to harness thermonuclear fusion as a future energy source, and also provides nearer-term radiation sources for weapon-effects studies. Fission reactor activities are aimed at developing improved fuels and enhanced safety for commercial power reactors.

The major facilities for conducting research in the physical sciences include several high-energy Van de Graaff accelerators, heavy-ion and high-current accelerators, ultrahigh vacuum facilities, gas-gun installations, high-intensity lasers, intense pulsed electron accelerators, and pulse reactors. (Item 1)*

MATERIALS AND PROCESSES

Materials and process activities maintain a balance between research and development to provide materials compatible with the extreme environments and performance requirements associated with nuclear ordnance.

Specific technical areas that have continuing emphasis include metallurgy, composites, surface characterization, thin film deposition, polymers, ceramics, and high-temperature characterization. Complete processing and fabrication facilities assure a capability for early

*See Highlights below.

evaluation and use of tailored materials. Efforts are focused on material applications involving structural and electronic materials, thermal and electrical insulation, radiation shields, and shock mitigation. Key elements in these efforts are functionability, reliability, and longevity.

This interdisciplinary approach to scientific materials engineering results from the recognition that many disciplines are required to understand, characterize, and apply materials, and from the fact that material design is an essential element in meeting the objectives of quality, functionality, and life. (Item 2)

APPLIED MATHEMATICS

Research in numerical mathematics provides support for scientific computing and typically leads to the development of new or improved computer programs. Many problems associated with the command and control of nuclear weapons and with the reliability and security of communication networks require mathematical research in the related disciplines of graph theory, combinatorics, and coding theory. Research in mathematical physics is resulting in a better understanding of material properties and wave propagation. Research on the theoretical foundations of a number of mathematical tools used by scientists and engineers is delineating more clearly the range and usefulness of these tools. Statistical research is carried out in support of reliability studies, system analysis, the design of experiments, and data analysis. *(Item 3)*

EARTH SCIENCES

The earth sciences are directed principally toward an understanding of the response of the upper layers of the earth (soil and rock) to dynamic loading. The disciplines of geology, soil mechanics, fluid dynamics, and engineering mechanics have been combined to solve specific earth-response problems that fall outside the scope of any one technical area. Penetration, drilling, and measuring the response of the earth to explosions and earthquakes are of prime importance. In problem areas encountered at these Laboratories, earth-material motions and strain rates are appreciably greater than are found in more classical studies of soil motion. Specific technical areas on which continuing emphasis is placed include dynamic stress analysis (as related to earth materials), terradynamics (phenomena attendant upon earth penetration by high-velocity projectiles), underground physics (the study of earth-material motions resulting from underground detonations), drilling technology, magma research, and the development of diagnostic instrumentation. The key element in each of these areas is the effort to understand the dynamic behavior of earth materials so that they can be characterized well enough to make specific problems solvable. Soil and rock are complex materials in terms of engineering properties, particularly during high loading rates and at high temperatures, and consequently there is a strong reliance upon empirical results.

AEROSCIENCES

Aeroscience activities represent a balance between applied research and the aeroengineering required to support technical programs. Studies are directed toward a greater understanding of mechanisms encountered in extreme flight environments that include velocities up to 8000 metres per second, altitudes from below sea level to over a million metres, and vehicle surface temperatures up to 4500 K. Areas of interest include aeroballistics, rocket aerodynamics, decelerator technology, experimental aerodynamics, atomic and fluid physics, aerothermodynamics, experimental aerophysics, atmospheric environmental studies, applied fluid dynamics, and aeromechanical design.

Research and development are supported by analytical techniques including computer modeling, and by laboratory facilities such as analog and hybrid computers, motion simulators, trisonic and hypersonic wind tunnels, arc jets, shock tubes, water tunnels, and parachute fabrication and testing equipment. (Item 4)

BIOSCIENCES

Biological programs are directed toward an understanding of the effects of environmental conditions upon living systems. Emphasis is on incorporating physical, chemical, and engineering principles, theories, and techniques into the resolution of biological problems. Results from this effort include models of the lethal effects of heat and ionizing radiation on microbiological systems, new microbiological sampling devices and techniques, new sterilization processes, computerized systems representing man's interaction with a plutonium-contaminated environment, new information about the effect of heat upon radiation-induced mutation, the behavior of bacteria on surfaces to be sterilized, and the usefulness of heat/radiation combinations in vaccine development. (Item 5)

SUMMARY OF CAPABILITIES

EXPLOSIVES, ELECTROCHEMISTRY, AND ELECTROMECHANISMS

A demand for components made to high standards of reliability, safety, and longevity for use in nuclear weaponry has required research and development to make possible an understanding of the mechanisms that control component operation, and to use these mechanisms for practical purposes.

Most of the components either generate or are actuated by electrical signals. Operational constraints have necessitated miniaturization, long-term material compatibility, and an ability to withstand severe environments.

Studies in explosives, particularly detonation physics and the chemistry of explosives, have led to reliable ways to use the sudden release of chemical energy. Chemical and thermal-conversion processes are used to release the energy stored in batteries. Studies in electromechanisms have resulted in miniaturized components for environment sensing, electrical switching, and timing.

The major facilities for conducting research and advanced development of electrochemical and electromechanical components are chemical laboratories, gas guns, fabrication facilities, and environmental testing and firing sites.

ELECTRONICS

The aim of electronics activities is to acquire an understanding of the physical properties of elements used in electronic circuits and the effects of fabrication and processing on these properties. Reliability is a basic requirement, and predictable response is necessary under extreme environments such as mechanical shock, intense radiation, and large temperature excursions. Studies of the properties of silicon as influenced by processing variables result in reliable and innovative active elements. Work on various methods of discrete component attachment aids in the miniaturization of hybrid circuits. Substrate and thin-film studies are leading to new electronic materials and providing improved assembly methods.

Vacuum tubes are designed that allow the rapid transfer of electrical energy and the generation of high-energy neutrons. Pulses of high-current, high-voltage electrical discharges are generated by the controlled depolarization of ferromagnetic and ferroelectric materials.

Facilities exist for building hybrid microcircuits and for evaluating prototype designs. There are large modern clean-room facilities for the fabrication of active semiconductor elements and large-scale integrated circuits. A laboratory area is available for fabricating neutron generator tubes and high-energy switching tubes. (Item 6)

QUALITY ASSURANCE

The quality assurance function consists of technical and management activities which provide a continuous and comprehensive evaluation of how effectively system design agencies and production contractors control the manufacturing system, how precisely procedures are followed, and how nearly a product conforms to specifications for performance, life use, maintainability, reliability, and safety.

To promote third-party objectivity, quality assurance evaluations are carried out by a Sandia organization which is independent of the project groups that were concerned with development, and which acts under the auspices of ERDA's Albuquerque Operations Office.

SAFETY AND RELIABILITY ASSURANCE

Safety and reliability responsibilities have necessitated the development of analytical and measurement techniques for evaluating system behavior in normal and abnormal environments. As a result of these evaluations, designs are sometimes modified or new design concepts introduced. Assessment technologies emphasize extensive use of computational models and data from simulation experiments and tests at subassembly and lower levels. This is necessary because full-scale demonstrations in anticipated final-use conditions are often forbidden by international agreements, or by ecological or economic conditions.

Safety and reliability studies are performed on such projects as nuclear weapons, conventional weapon subassemblies, nuclear power reactors, special transport vehicles, and ground-based and satellite sensor systems.

Both safety and reliability investigations are conducted by specialists outside the project groups to encourage an independent assessment approach.

* * * * * * *HIGHLIGHTS* * * * * * *

Item 1. *Electron-Beam-Ignited Chemical Laser*

The REBA accelerator (Figure 1), developed by Sandia in 1967 for weapon-effects studies, is used in the exploration of methods to develop high-power lasers. In one experiment a magnetic field is used to guide electrons in a drift chamber filled with hydrogen and fluorine. The gas mixture is ignited, producing the most intense laser pulse ever recorded. 5000 joules for 20 billionths of a second.

Item 2. *Melting and Solidification Laboratory*

A melting and solidification laboratory has been established for the pilot-scale production of homogeneous alloys of unique chemistries. Specific alloy chemistries are prepared in a 500-pound-capacity vacuum-induction furnace and cast into electrode feedstock for the vacuum-arc remelt furnace shown in Figure 2. Ingots up to 10 inches in diameter can be produced by the consumption of feed electrodes in a low-pressure, 15,000-ampere arc. These highly instrumented furnace systems provide significant quantities of well-characterized material for alloy-development studies, demonstrating how superior structural materials can be produced through enhanced process controls.

Item 3. *Advanced Numerical Techniques*

Stress- and shock-wave-propagation computer programs are developed for a more complete understanding of stress-wave mechanics. Codes are used to analyze system and component designs, reducing reliance on expensive experiments. The ability of two-dimensional computer codes to solve difficult problems accurately is illustrated in Figure 3. A 1.27-cm-thick steel armor plate is impacted by a 0.95-cm-diameter nylon sphere at 5182 m/s. The 13-GPa polymorphic phase change in iron, the correct spall strength, an accurate material failure model, and a high degree of numerical resolution were required in the solution.

Studies of high-velocity impacts include predictions of damage to nuclear reactor vessels from fragments such as turbine blades dispersed in an internal accident, and from tornado-borne debris.

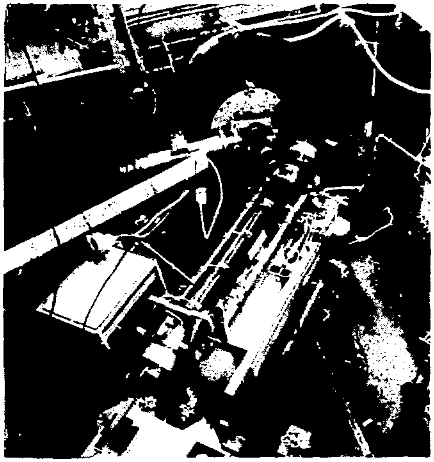


Figure 1. Relativistic electron beam accelerator (REBA).

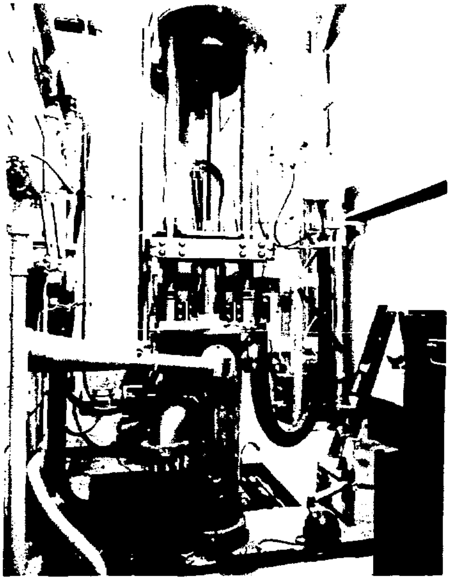
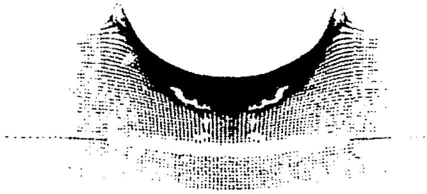


Figure 2. Vacuum-arc remelt furnace.

SUMMARY OF CAPABILITIES

Eulerian code solution with
13-GPa phase transition



Eulerian code solution without
13-GPa phase transition

Lagrangian code solution with
13-GPa phase transition

Experiment

Figure 3. Comparison of code predictions with results of hypervelocity impact experiment

Item 4. *Hypersonic Wind Tunnel*

The hypersonic wind tunnel (Figure 4) is used for aerodynamic testing of scaled models of high-performance flight vehicles, and for applied-research studies in fluid dynamics. Flow Mach numbers of 3.5, 5, 8, 11, and 14 can be obtained in a 45-cm-diameter test section. The facility includes comprehensive instrumentation and data-acquisition systems.

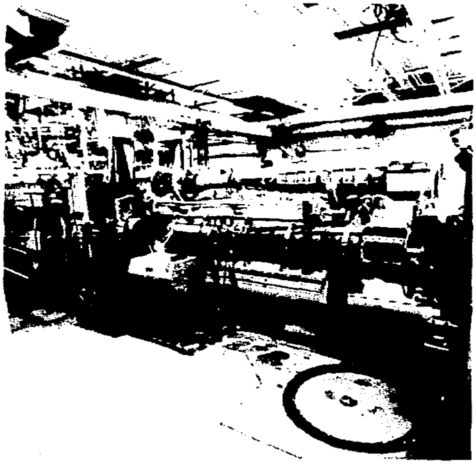


Figure 4. Hypersonic wind tunnel.

Item 5. *Bacteria Inactivation*

A biosciences project has as one of its objectives the development of a technology to use radioisotopic by-products from reactor fuel rod reprocessing to deactivate municipal sewage sludge. A potentially beneficial use of heat combined with radiation from cesium is the eradication of pathogenic organisms so that the sludge may be used on crop-producing land or in livestock feeding. The optimal combination of radiation and heat is being sought through studies of the inactivation of polio virus, adenovirus, coliform bacteria, fecal streptococci, Salmonella species, and Ascaris ova. Figure 5 depicts typical coliform inactivation data. Modification of the physical and chemical characteristics of sludge (such as filterability, odor, and chemical and biological oxygen demand) by heat and radiation combinations is also being studied. The activity includes experimental system design and fabrication, pilot plant design, determination of cost factors, the study of sludge uses and accruing benefits, and safety analyses.

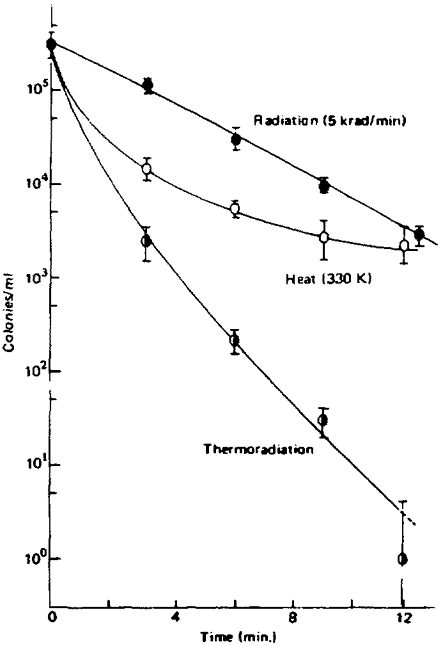


Figure 5. Inactivation curves for heat, radiation, and their combination (thermoradiation) in the treatment of coliforms in sewage sludge.

Item 6. *Hybrid Microcircuit Technology*

A continuing effort to advance thin film and hybrid-circuit techniques provides a foundation for fabrication, materials, and the interconnections of discrete components. As an example, the hybrid microcircuit shown in Figure 6 is used in locking mechanisms to protect nuclear materials from unauthorized use. Hybrid microcircuit technology is highly developed and has found application in other protective components and intrusion detectors for special nuclear materials, satellites, radars, and applications requiring rugged, compact circuits such as earth penetrators, new drilling techniques, and [illegible] ground test instrumentation.

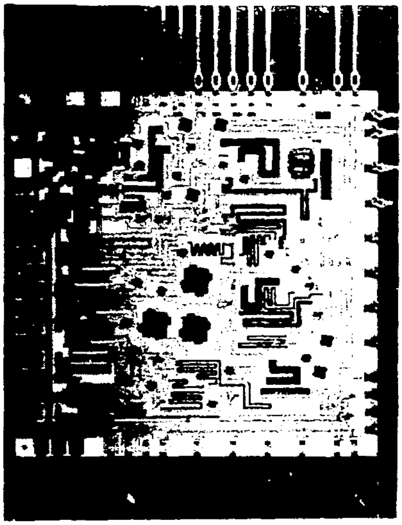


Figure 6. A hybrid microcircuit. The actual size is 6 square centimetres.

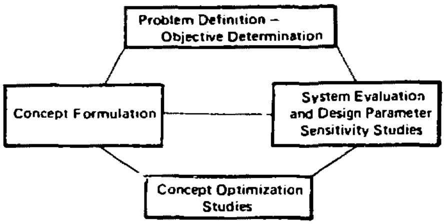
SUMMARY OF CAPABILITIES

ANALYSIS AND TESTING

SYSTEMS ANALYSIS

The objective of systems analysis activities is to aid in deciding among alternative systems and concepts. This is accomplished by evaluating the relative utility and costs of competing options within the appropriate environment. Areas of active study include nuclear and conventional weapon systems, energy extraction and conversion, environment analyses, security systems for weapons and materials in nuclear fuel cycles, and biological systems. Typically, the studies seek to evaluate the relative worth of new concepts and to provide an understanding of parameter sensitivities that can lead to system improvements.

The outline below describes the major steps in almost every system study.



The systems analysis function may begin at any point in this schematic and feed forward or back to previous steps, as indicated. The object of such iterations is to formulate, evaluate, and/or optimize a system or alternative systems on the basis of a common set of objectives. In addition to identifying system options or alternatives the studies provide early insight into critical technology requirements. (Item 1)*

ENGINEERING ANALYSIS

This function is concerned with calculating the responses of designs to their environments. Structural mechanics is used to aid in determining a design configuration and in choosing materials suitable for the loads to be encountered in practice, particularly in severe dynamic environments.

*See Highlights below.

Stress-wave analysis centers on the propagation of stress waves arising from impact, explosions, transient radiation, and other extreme environments. Chemical analysis is used to determine the initiation and detonation characteristics of explosives. Heat-transfer studies confirm the performance of heat-exchange systems, thermal protection materials, and rotating machinery based on various thermal cycles and phase changes. Aerodynamic calculations predict the behavior of vehicles in free and propelled flight. Environment analysis is used to define the conditions a product might encounter during its lifetime. The analysis of control systems comes into play when environment-sensing devices, control mechanisms, and decision-making and guidance functions are combined. The design of electronic packages relies on circuit analysis. Nuclear engineering analyses are directed toward pulsed reactor development, design, and operation. Reactor safety analysis relates to hypothetical disruptions of nuclear reactor operations.

As a necessary adjunct to successful engineering computations, both mechanical and thermal material properties are determined.

The major facilities used in engineering analysis are large digital and analog computers, static test facilities, wind tunnels, and vibration test facilities. Numerous pieces of equipment are used to determine material properties. (Item 2)

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. Environments simulated include shock, vibration, surface impulse, blast loads, thermal, aerodynamic, underwater, and electromagnetic. Radiation sources have been developed to simulate nuclear effects tests. Pulse reactors provide a mixed neutron-gamma exposure. Steady-state neutron and gamma irradiation are provided by a neutron generator and cobalt and cesium radiation sources. Bremsstrahlung x-ray and electron-beam exposures are performed using pulse accelerators. Test facilities used primarily in support of exploratory research and development 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 materials characterization 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 holometry, 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 the 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. (Item 3)

SUMMARY OF CAPABILITIES

INSTRUMENTATION AND DATA SYSTEMS

An extensive instrumentation and data reduction activity is maintained. Many advanced designs now in development must operate in extreme environments such as those encountered in space, in high radiation fields, or under severe mechanical, thermal, and electromagnetic loads. The instrumentation activity provides instruments that measure characteristics of environments, measure responses and performance of materials and systems operating in them, and locate accurately the position of systems in the environment. To fulfill these tasks, new instrumentation systems are developed and existing techniques modified. Instrumentation is fielded in conjunction with design and testing activities.

Data processing and data reduction are integral activities that provide test information in various forms, including charts, graphs, photos, movies, or special forms, depending upon needs. (Item 4)

* * * * * * *HIGHLIGHTS* * * * * * *

Item 1. *Nuclear Material Security*

A concept has been developed that involves drilling and casing a deep hole of reasonably small diameter to create a secure underground vault for weapons or nuclear materials (Figure 1). Access to the vault is controlled through the use of a security door operated by a buried coded switch. All other features necessary for a complete security system were conceptually designed and evaluated.

A study of this and other alternative storage concepts was prompted by increasing concern about terrorist threats and by the desirability of reducing readily available, full-time guard forces, such as are demanded by present storage methods.

Critical factors that were studied relating to weapon storage included potential security threats, safety, initial and operating costs, vulnerability, logistics, and future flexibility.

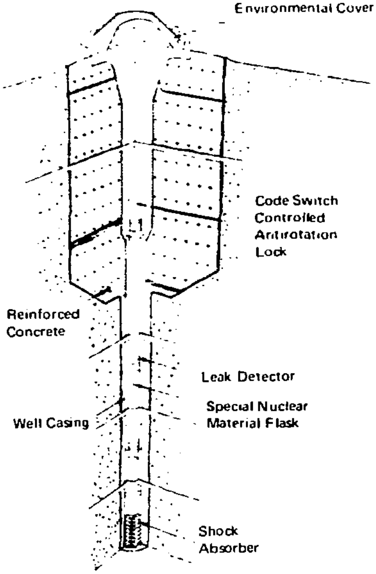


Figure 1. Underground vault for storing nuclear materials.

SUMMARY OF CAPABILITIES

Item 2. *Three-Dimensional Static Stress Analysis*

Analytical capability has been developed to perform three-dimensional static stress analyses of shells and solid structures subjected to mechanical and thermal loading. Analyses are based on assumptions of infinitesimal strain and linear elastic material behavior. A capability exists to perform elastic-plastic three-dimensional calculations. Implied in this capability is the use of input and output data processors, which are essential in three-dimensional analyses. This type of analysis finds application in structural, electrical, and electromechanical components. As an example of the technology, Figure 2 shows the three-dimensional finite-element idealization of an encapsulated electrical component. When subjected to [illegible] det[illegible]ns as shown in Figure 3. Calculated stress contours on a particular plane can also be plotted, as shown in Figure 4.

Figure 4. Maximum principal stress contours on a plane through the structure.

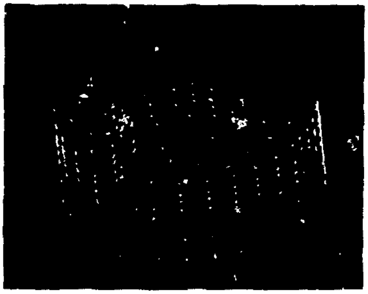


Figure 2. A three-dimensional finite-element mesh idealization of an encapsulated electrical component.

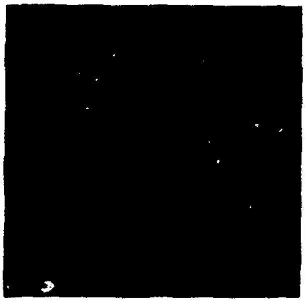


Figure 3. Deformed shape of the mesh on a plane through the structure.

Item 3. *Nuclear Weapon Test and Evaluation*

Testing and evaluation of materials, components, and systems play key roles in the research and development of nuclear ordnance. Extensive facilities for environment simulation, research, development, evaluation, and field testing, and associated instrumentation and data analysis systems have been developed. Figures 5 through 7 show examples of test facilities.

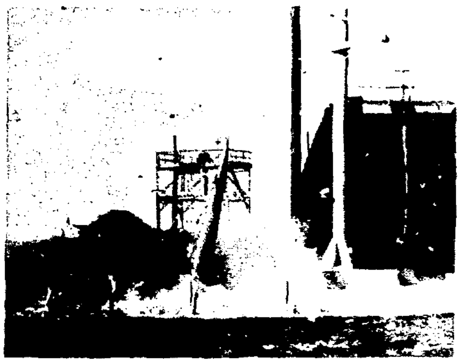


Figure 5. An explosively driven shock tube is used to evaluate the response of a vehicle to blast loading.

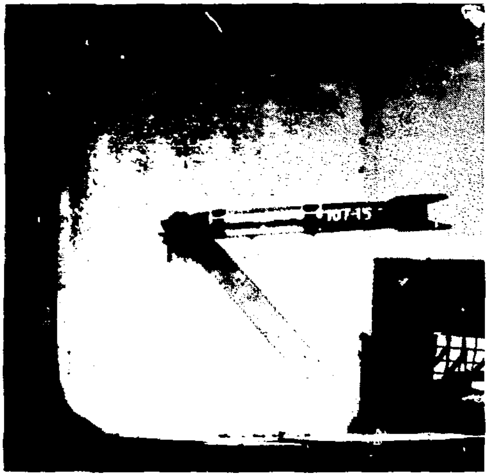


Figure 6. A rocket-propelled sled drives a test vehicle into a concrete target. Impact angle was 45 degrees. The structural response of the vehicle and the timing sequence of the components operation were evaluated.

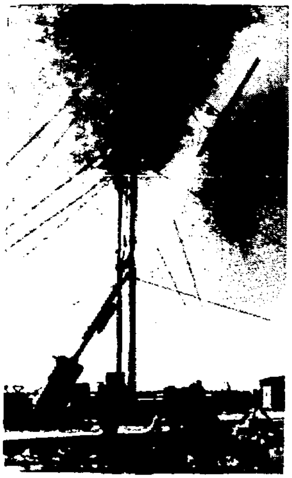


Figure 7. A rocket is used to accelerate a prototype nuclear bomb into a hard target. Behavior of weapon components and structure is measured using optical and electronic instruments.

Item 4. *Atmospheric Research*

Concern about atmospheric pollution has been intensified with the realization that potentially serious deleterious effects on the earth's protective ozone layer may be caused by stratospheric aircraft, fluorocarbon chemicals, and atmospheric testing of nuclear weapons. The long-term Sandia atmospheric research program has become of central importance to solution of the stratospheric problems; it is the principal correlated multi-instrument national study of the stratosphere and troposphere. The program is carried out in cooperation with research teams from twelve university, federal, and industrial laboratories, with Sandia providing project engineering and scientific coordination in addition to scientific experiments. Other atmospheric environmental programs include lower-atmosphere pollution studies from aircraft and manned balloons (Figure 8), and rocket-based studies of the ionosphere and mesosphere.

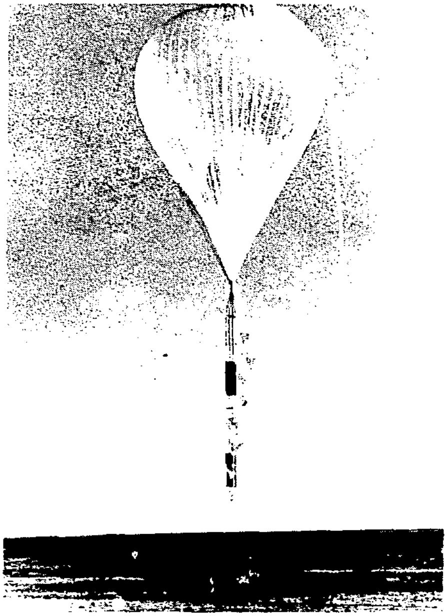


Figure 8. Termination of a scientific manned balloon flight. The tropospheric balloon carried instruments for studying the chemical evolution of air pollutants.

SUMMARY OF CAPABILITIES

SUPPORT FUNCTIONS

DESIGN DEFINITION AND FABRICATION

Research and development programs are supported by developing and applying computerized design and record-keeping systems; maintaining records of designs, specifications and changes, and coordinating with contractors who produce parts of systems; and maintaining drawings of designed systems.

Processes are developed and hardware fabricated to provide experimental vehicles and models required by engineering and scientific organizations. Complementing the fabrication and development facilities are inspection, equipment repair, and process engineering services, as well as calibration services which interact with Sandia's Primary Standards Laboratory.

COMPUTATION SYSTEMS

The computing centers and their associated technical support organizations at both Albuquerque and Livermore have the responsibility of planning, adapting, and operating large-scale digital computer facilities in general support of the scientific and engineering community of the Laboratories. Such modern, large-scale computers have become essential to the solution of such problems as the modeling of complex systems, component design and development, and the detailed simulation of physical phenomena. A growing number of smaller digital computers are integrated into specialized facilities supporting specific areas of research and development such as activities in experiment control, data acquisition, and test monitoring. A few main-line computers are devoted to management information and business data processing.

The central computing facilities are presently based on Control Data Corporation scientific computer systems. The Albuquerque facility consists of three CDC-6600's sharing a common mass-storage subsystem as well as extended core storage. A CDC-7600 is scheduled for operation in January 1976. The Livermore facility contains an additional CDC-6600, also with an extended core capability. Remote job entry and interactive computation are increasingly emphasized. Time-sharing is accommodated at both centers but is represented more extensively at Albuquerque where a PDP-10 computer system is devoted exclusively to that function.

MEASUREMENT STANDARDS

The aim of this activity is to assure measurement agreement among participating research, development, design, production, acceptance, and quality assessment groups and agencies. To this end it promotes a common administrative and technical base of procedure and capability, embodied in physical references and practices of high accuracy and sophistication. When possible, values are referred to those defined by the National Bureau of Standards.

The ERDA Primary Standards Laboratory, which is managed by Sandia Laboratories, is oriented to the development and maintenance of primary reference standards and their application to the calibration of other reference standards in the overall standards system. A research and development program in measurement technology provides new standards and accuracy levels when required. Program and measurement activities of participating groups and agencies are examined continuously to assure balance and compatibility in standards efforts. Consultation service is provided on measurement and standardization problems, and technical audits and surveys of contractor standards laboratories are conducted regularly.

ENVIRONMENTAL HEALTH

The primary responsibility of the environmental health function is the evaluation and control of hazardous materials and conditions. The evaluation and control of toxic materials, nonionizing radiation such as laser beams and microwaves, and ionizing radiation from radiation machines and radioactive sources, are examples of the activities of environmental health programs. A chemical laboratory is operated for the analysis of toxic and radioactive substances and to provide an index of internal exposure of personnel to toxic and radioactive materials. Instrumentation is developed and maintained for environmental health activities. A dosimetry program measures personnel exposure to external ionizing radiation. Reentry safety control and effluent documentation support are provided for underground nuclear tests.

INFORMATION SCIENCE

The information science activity functions within the framework of the technical library, and is oriented toward the efficient dissemination of information to technical and administrative personnel. Computerized systems are used to collect, process, and circulate books, reports, and other literature. Current awareness, reference, translation, and literature-search services are also provided.

APPENDIX

APPENDIX

FACILITIES

The administrative, laboratory, shop, storage, and special facilities maintained by Sandia at its three locations include:

Location	Acres	Number Buildings	Thousand Sq. Ft.	Cost $ Million*
Albuquerque, NM	2,835**	285	2,233	247.5
Livermore, CA	161	45	161	48.3
Tonopah, NV	369,280***	39	60	20.3

*Includes facilities, equipment, land, and utilities

**An additional 47,000 acres are available on co-use agreement with the Air Force

***Used by permit from and operating agreement with the Air Force

Major Technological Assets

Over 25 years of operation, Sandia has acquired a wide range of specially designed and constructed facilities for ordnance engineering. Recently, some of these, together with new facilities being developed, have been applied to energy problems. Some individual facilities are among the largest in the country, but it is the broad scope of special facilities and equipment that makes the activities in engineering, testing, and basic sciences particularly effective. Because of the specialized demands most of the equipment and facilities were either designed or modified by the Laboratories.

Testing facilities at the three locations represent an investment of more than $106 million, providing capabilities for environment and radiation simulation, aerodynamic and material characterization, nondestructive testing and quality-assurance evaluation, and field assessments of components, weapons, and delivery modes. Special facilities include some of the nation's largest centrifuges and shock tubes, a radiant-heat facility, a transonic wind tunnel, a sled track, and aerial cable facilities on which test specimens are accelerated downward by rocket sleds. Facilities for the investigation of aerodynamic and material characteristics of components and full-scale flight vehicles represent a further investment of $27 million. Nondestructive and quality-assurance testing equipment and facilities total $30 million in acquisition cost. A new advanced Tritium Research Laboratory will provide capability to handle safely a variety of experiments with tritium compounds.

In the physical sciences, several Van de Graaff and Cockroft-Walton accelerators are used in surface physics research and microelectronics development; three pulsed reactors (one of which can deliver 4×10^{15} neutrons per square centimetre in a 4.7 millisecond pulse) are employed for reactor development and reactor safety research; and the nation's most intense relativistic electron beam accelerators are being used in pulsed fusion research, in laser excitation, in nuclear effects studies, and in collective acceleration of ions to ultrahigh energies. These accelerators are also used in the laser fusion program to excite large-volume laser media to record levels. One of the reactors has been used to pump a carbon-monoxide laser of Sandia design. Investment: $19 million.

Computation facilities at all locations represent an investment of $32 million. Scientific computing is currently done with five CDC-6600 computers, and a CDC-7600, including batch processing and interactive graphics capabilities and an off-line computer output microfilm system that can also generate motion pictures in color. Business and management information needs are handled by a dual-processor UNIVAC 1108 and CDC-3600. Requirements for unclassified computation in a time-sharing mode are satisfied by an 80-terminal PDP-10. Instrumentation and data needs at the test sites are handled by a CDC-6400, a CDC-3100, two PDP-124's, and XDS-930. Flight-simulation facilities include several analog and hybrid computers. Other computers are used to control device testers and acquire and reduce data in the microelectronics laboratory, for laser diagnostics, and for numerically controlled machine tools.

Investment in facilities dedicated to design, fabrication, and process development exceeds $12 million. Included are computers to aid in design; a complete machine shop whose conventional equipment is supplemented by five-axis numerically controlled milling facilities, and a miniaturization shop; a welding and joining laboratory (including microwelding); a specialized glass-fabrication shop; a ceramics fabrication laboratory; a combustion laboratory, including equipment for laser-based Raman spectroscopy; a plastics and composites (such as carbon-carbon) fabrication and processing facility; a laboratory for melting special alloys; and heat-treating and finishing facilities for flame and plasma spraying, plating, and coating.

Sandia maintains for ERDA a Primary Standards Laboratory wherein technical procedures and capabilities are reflected in physical references and practices of high accuracy and sophistication. A hierarchy of standards laboratories and calibration stations carries the units of measurement to the working level among all prime contractors in the nationwide weapon-production complex. Facilities and equipment valued at $4.5 million are used to maintain measurement standards in direct and alternating current, microwave, electrical pulse, radiation, mechanical, and environmental areas.

A laboratory is maintained for conducting research on the mechanisms that control the response of electronic elements and for studying the processing techniques involved in hybrid microcircuitry and semiconductor development. Hybrid microcircuitry developed at Sandia has found application in the protection of nuclear weapons and materials, weapon electronic components (resulting in significant reductions in size and weight), and in providing down-hole power for advanced drilling techniques.

APPENDIX

EDUCATIONAL RESOURCES

Highest Degree Attained		Number on Roll
PhD		709
Masters		929
Bachelors		1277
	Total	2915
Bachelors of Technology or Associates		1155
Major Fields of Technical Staff		
Engineering		1594
Physics		301
Mathematics		197
Chemistry		170
Earth Sciences		61
	Total	2323

An interchange between the laboratory and universities is achieved through the visiting professors, adjunct professorships, and joint appointment programs. Continuing education of the laboratory staff is achieved through the doctoral support, one-year-on-campus, and tuition refund programs and by noncredit in-house courses.

APPENDIX

BUDGETARY INFORMATION

The estimated operating budget for fiscal year 1977 is $361.9 million: 81percent of the funding is by ERDA and the remaining, about $67 million, from other federal agencies, primarily the Department of Defense and the Nuclear Regulatory Commission. The average number of full-time employees for fiscal 1977 to date is 7175.

All facilities are owned and funded by the federal government, and are operated by the Bell System for ERDA on a no-fee, no-profit contract with the Western Electric Company.

The authorized investment in plant and equipment in February 1977 was $360 million.

OPERATING BUDGET

Actual Cost for FY 76 and Estimated Cost for FY 77*
($ in Millions)

Activity	FY 76 (Excluding 1976T)	FY 77
For ERDA		
Weapons	$196.3	$227.3
Nuclear Material Security	4.6	12.8
Electron Beam and Laser Fusion	8.5	9.8
Fossil Energy	3.9	6.8
Solar, Geothermal, and Advanced Energy Systems	8.7	24.1
Conservation	1.0	2.4
Nuclear Energy	5.4	8.3
Environment and Safety	2.1	3.0
Total ERDA	$230.5	$294.5
For Other Federal Agencies		
Department of Defense	$ 47.5	$ 41.6
Nuclear Regulatory Commission	5.3	17.8
Other	3.8	7.7
Total Other Federal Agencies	$ 56.6	67.1
Miscellaneous	$ 0.1	$ 0.3
TOTAL	$287.2	$361.9

*Compiled March 1977

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